

(NASA-TM-84180) NASA/HAA ADVANCED
ROTORCRAFT TECHNOLOGY AND TILT ROTOR
WORKSHOP. VOLUME 6: VEHICLE CONFIGURATION
SESSION (NASA) 256 p HC A12/MF A01 CSCL 01C

N82-23242

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NASA

ADVANCED ROTORCRAFT TECHNOLOGY AND TILT ROTOR WORKSHOPS

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VOLUME VI
Vehicle Configuration
Session

HAA/NASA
ADVANCED ROTORCRAFT TECHNOLOGY
WORKSHOP

December 3-5, 1980
Palo Alto, California

VOLUME VI

VEHICLE CONFIGURATION SESSION

VOLUME VI
VEHICLE CONFIGURATION SESSION
CONTENTS

	<u>Page</u>
CHAIRMAN'S REPORT	VI-1
OVERVIEW - NASA TECHNICAL PROGRAMS	VI-21
HIGH SPEED VEHICLE CONFIGURATIONS SUBSESSION	VI-43
LARGE ROTORCRAFT VEHICLE CONFIGURATIONS SUBSESSION	VI-165

CHAIRMAN'S REPORT

HAA/NASA ADVANCED TECHNOLOGY WORKSHOP

VEHICLE CONFIGURATION SESSION

CHAIRMAN

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Bell Helicopter Textron

TECHNICAL SECRETARY

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NASA-Ames Research Center

The description of the NASA technical programs was performed by William Snyder of NASA-Ames Research Center.

High Speed Vehicle Configurations Subsession

Chairman

Lewis Knapp
Sikorsky Aircraft

Members

Rodney K. Wernicke
Bell Helicopter Textron
(Tilt Rotor)

Leo Kingston
Sikorsky Aircraft
(X-wing)

Andrew Logan
Hughes Helicopters
(Compound concepts)

Ted Carter
Sikorsky
(Advancing blade)

Frank McHugh
Boeing Vertol
(High speed)

Members

William Thompson
Air Logistics, Inc.

Capt. M. J. Evans
British Airways Helicopters

John Magee
Ames Research Center

Dr. Michael Scully
U.S. Army Research

Elmer (Tug) Gustafson
Tug Gustafson Associates

Thomas C. West
FAA

Large Rotorcraft Vehicle Configurations Subsession

Chairman

Gordon Fries
Boeing Vertol

Members

Ted Carter
Sikorsky Aircraft
(Multi-lift)

Robert E. Head
Hughes Helicopters
(Single rotor, tip drive)

John Schneider
Boeing Vertol
(Multirotor heavy lift)

Members

Frank Piasecki
Piasecki Aircraft Corp.
(Hybrid airship)

Hal Symes
Evergreen Helicopters

James Lematta
Columbia Helicopters

USER NEEDS

From the user presentations, Volume II, prioritized needs judged to be applicable to NASA vehicle configuration research were developed. It was recognized that the helicopter user community is highly varied, ranging from light ambulance to heavy lift and offshore transport operators and that their future rotorcraft needs are therefore quite varied. Nevertheless, agreement was reached on a unified list of operator needs. This list, shown in Table I, was divided into three groups of descending priority. While they have been prioritized, it is emphasized that even those in the third category received specific attention from the operators and are worthy of investigation.

Within each group, there is no relative priority to the needs given. Opposite each need are, where appropriate, technical requirements and proposed research actions. The proposed actions are, to the extent possible, restricted to those that are vehicle configuration dependent. The user needs stated in Table I constitute a check list against which proposed advanced rotorcraft configurations can be compared to determine their suitability for commercial applications. The following comments clarify the user needs.

First Priority

Safety - Not necessarily a configuration determinant, but obviously of prime interest to all commercial rotorcraft operators. Emphasis was placed on the elimination of any failure mode that could lead to an accident.

Zero Rejected Takeoff Distance - The one-engine-inoperative rejected takeoff distance as defined by the FAA for Category A rotorcraft operations.

Reliability - A key step in reducing the cost of operation. Premature removal of expensive components must be minimized.

TABLE I

WORKSHOP SUMMARY FORM

WORKSHOP TECHNOLOGY AREA Vehicle Configurations SUB-AREA High Speed Concepts/
Large Rotorcraft Concepts

USER NEEDS	TECHNOLOGY REQUIREMENT	PRESENT STATUS	PROPOSED R&D ACTION (NASA/INDUSTRY)
1. <u>FIRST PRIORITY</u>			
Safety	An overriding consideration		Perform design studies of proposed configurations to identify at an early point any unsafe characteristics.
Zero rejected Takeoff Distance, OEI	Effects of: <ul style="list-style-type: none"> - Power required in low speed flight - Rotor disposition for multi-rotor configurations 		Conduct flight tests to determine takeoff performance of single-rotor, tandem-rotor, and side-by-side rotor aircraft. Correlate with analysis.
Reliability	Not a direct configuration research driver		None
Noise	Understanding of rotorcraft external noise sources, particularly as influenced by aerodynamic interference during takeoff and landing		Measure noise generated by current advanced rotorcraft
Speed	See separate listing, Table II		Develop theory to predict noise

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TABLE I (Cont'd)

WORKSHOP SUMMARY FORM

WORKSHOP TECHNOLOGY AREA	Vehicle Configurations	SUB-AREA	High Speed Concepts/ Large Rotorcraft Concepts
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USER NEEDS	TECHNOLOGY REQUIREMENT	PRESENT STATUS	PROPOSED R&D ACTION (NASA/INDUSTRY)
2. <u>SECOND PRIORITY</u>			
Range	A function of: - propulsive efficiency - weight of fuel carried - L/D - specific fuel consumption of engine(s)		initiate research tasks directed at aerodynamic improvement of propulsive devices, reduction in weight empty to gross weight ratio and drag reduction
Fuel efficiency	- increased nautical miles per pound of fuel consumed		For reduced engine sfc, see the Propulsion Session See above
Protected/No tail rotor	Multi-rotor configurations, alternate antitorque systems for single-rotor helicopters		None
Mission flexibility	A fallout of other vehicle attributes		None
Ground disturbance	Understanding of disc loading, gross weight, rotor disposition effects		Literature survey Flight and tiedown tests with existing rotorcraft of differing configuration and gross weight
Large size	See separate listing, Table II		

TABLE I (Cont'd)

WORKSHOP SUMMARY FORM

WORKSHOP TECHNOLOGY AREA	Vehicle Configurations	SUB-AREA	High Speed Concepts/ Large Rotorcraft Concepts
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USER NEEDS	TECHNOLOGY REQUIREMENT	PRESENT STATUS	PROPOSED R&D ACTION (NASA/INDUSTRY)
3. <u>THIRD PRIORITY</u> Crashworthiness) Compact) Agility) Load handling)	Not configuration research drivers		None

External Noise - Already a limiting factor to rotorcraft operators flying near populated areas. It will become more critical as the number of helicopters increases and as noise control regulations are promulgated.

Speed - Important from two aspects: time saved, which in itself is essential to the success of many rotorcraft applications, such as medical evacuation; and increased productivity, where performing a given transportation task in a reduced time tends to lower those costs which are flight hour dependent. Speeds as high as 300 knots were cited as desired by some operators.

Second Priority

Range - Increases are necessary if rotorcraft are to continue to find application in one of their prime markets, offshore oil support. For this market, a need was expressed for ranges out to 600 miles by 1990 and 1000 miles by 1995.

Fuel Efficiency - With the increasing cost of fuel, it has become a major factor in rotorcraft direct operating costs. Recognizing the vulnerability of the U. S. to foreign oil-producing countries, fuel efficiency is not only a matter of direct operating cost reduction; it is a matter of national concern.

Protected/No Tail Rotor - Certain applications, such as air ambulance and heavy lift, frequently require flights from congested areas that place a premium on rotorcraft size and the need for a protected tail rotor. Better still, would be the complete elimination of the tail rotor.

Flexibility - Rotorcraft that can perform at reasonable effectiveness and cost over a wide variety of operating conditions.

Ground Disturbance - An increasingly critical factor as rotorcraft size increases, this refers primarily to the downwash effects on personnel and structures.

Large Size - Not only to carry large, very heavy external loads over short distances (the traditional flying crane), but also larger transport rotorcraft which would benefit from the trend towards reduced seat mile costs as size increases.

Third Priority

Crashworthiness - Emphasis on fuel systems.

Compact - For operators who must fly from congested areas. Relates directly to the Protected Tail Rotor item in the Second Priority category.

Agility - Moving with positive control and precision when near obstructions, such as when landing at an oil rig, at a city center heliport, or when performing in police, firefighting or ambulance roles.

Load Handling - Faster loading and unloading of cargo, particularly as rotorcraft become larger.

The two user needs considered most amenable to attack through vehicle configuration research--high speed and large size--were the subjects of special panel discussions. Each panel, which consisted of representatives from rotorcraft user organizations, manufacturers, and government agencies, discussed various candidate rotorcraft configurations and developed recommendations for NASA research. These recommendations should be combined with those indicated in Table I to give a complete list of proposed research actions that are vehicle configuration dependent. A summary of each panel discussion follows.

HIGH SPEED VEHICLE CONFIGURATIONS PANEL

The members of this panel were:

Lewis Knapp	Subchairman
John Magee	NASA
Mike Scully	Army
Tug Gustafson	Independent
Tom West	FAA
Rod Wernicke	Manufacturer
Leo Kingston	Manufacturer
Andy Logan	Manufacturer
Ted Carter	Manufacturer
Frank McHugh	Manufacturer
Bill Thompson	User
Mike Evans	User

Five high speed rotorcraft configurations were considered: the high speed helicopter, compound helicopter, ABC, Tilt Rotor, and the X-wing. The technology requirements and the recommended actions are summarized in Tables I and II.

High Speed Helicopter

The application of the products of the fundamental rotor research recommended during the Aerodynamics and Structures Session of this workshop will in itself produce helicopters with increased cruise efficiency and higher speeds. Concurrent with the incremental increases in helicopter speed anticipated from the fundamental rotor research, it is recommended that a more aggressive program be directed specifically at achieving a marked increase in helicopter speed. Small scale model tests have indicated that it may be feasible to operate a helicopter rotor in a propulsive mode at speeds in the 185- to 225-knot range. To further investigate this potential, it is recommended that the preliminary

TABLE II

WORKSHOP SUMMARY FORM

WORKSHOP TECHNOLOGY AREA Vehicle Configurations SUB-AREA High Speed Concepts/
Large Rotorcraft Concepts

USER NEEDS	TECHNOLOGY REQUIREMENT	PRESENT STATUS	PROPOSED R&D ACTION (NASA/INDUSTRY)
Speed	<p>Configurations considered:</p> <p><u>High Speed Helicopter</u></p> <p>Rotor operation at high inflow, advance ratio and Mach number</p> <p>High speed airfoils</p> <p>Drag reduction</p> <p><u>Compound</u></p> <p>None required</p> <p><u>ABC</u></p> <p>Flight envelope expansion</p> <p>Integrated propulsion system with wide rpm range</p> <p>Rotor hub drag reduction</p> <p>Reduced weight empty and improved rotor performance</p>		<p>Define high speed helicopter</p> <p>Perform small-scale model tests</p> <p>Develop flightworthy full-scale rotor</p> <p>Test in NASA 80 x 120 foot wind tunnel and in flight</p> <p>None</p> <p>Complete XH-59A flight tests</p> <p>Develop technology for an integrated engine and propulsor to operate efficiently over a wide rpm range</p> <p>Fly available rotor head fairing</p> <p>Study rotor weight benefits from use of composite materials, performance benefits from optimized aerodynamics</p>

TABLE II (Cont'd)

WORKSHOP SUMMARY FORM

WORKSHOP TECHNOLOGY AREA	Vehicle Configurations	SUB-AREA	High Speed Concepts/ Large Rotorcraft Concepts
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USER NEEDS	TECHNOLOGY REQUIREMENT	PRESENT STATUS	PROPOSED R&D ACTION (NASA/INDUSTRY)
	Vibration alleviation		Investigate higher harmonic control for vibration alleviation in conjunction with FBW
	Effect of size		Determine effect of size on design for gross weights over 40,000 lb
	<u>Tilt Rotor</u>		
	Flight envelope expansion		Continue XV-15 flight tests
	Engines that operate efficiently over wide rpm range		Develop technology for engines to operate at high power, low sfc over wide rpm range
	Drag reduction		Investigate drag reduction, reduced empennage size, different empennage configurations
	Reduced weight empty		Study benefits of FBW and composite wing
	Improved rotor performance		Continue NASA Advanced Technology blade development
	Effect of size		Determine effect of size on design for gross weights over 40,000 lb
	<u>X-wing</u>		
	Fundamental technology		None - pending outcome of ongoing DARPA program

TABLE II (Cont'd)

WORKSHOP SUMMARY FORM

High Speed Concepts/
Large Rotorcraft Concepts

Vehicle Configurations

WORKSHOP TECHNOLOGY AREA

SUB-AREA

USER NEEDS	TECHNOLOGY REQUIREMENT	PRESENT STATUS	PROPOSED R&D ACTION (NASA/INDUSTRY)
Large Size	<p>Configurations considered:</p> <p><u>Tip driven, Single rotor</u></p> <p>Not applicable pending results of reassessment</p> <p><u>Tandem rotor, Shaft driven</u></p> <p>Transmission design</p> <p>Large rotorcraft technology base</p> <p><u>Multi-Lift</u></p> <p>Master-slave control laws</p> <p>Interconnect beam structural concepts</p> <p><u>Hybrid</u></p> <p>Flight evaluation</p>		<p>Reassess in view of today's technology</p> <p>Bench test XCH-62 transmissions</p> <p>Evaluate completing XCH-62 for flight test</p> <p>Develop control laws on NASA simulator</p> <p>Consider flight demonstration</p> <p>Reassess following completion of current program</p>

design of a high-speed helicopter be performed to determine realistic values of parasite drag with the associated body attitude and that the performance and dynamic characteristics be confirmed through Mach and Fronde-scaled model tests. Upon completion of these design studies and small-scale model tests, a full-scale flightworthy rotor should be fabricated and tested in the NASA 80 x 120 foot wind tunnel and in flight. In conjunction with the high-speed helicopter, as well as with the other high-speed configurations considered at this workshop, research should be directed at the overall problem of drag reduction.

Compound Helicopter

This rotorcraft configuration has been explored in the past by all major U. S. helicopter companies, including the flight testing of a number of research aircraft and one compound intended for operational use, the AH-56 Cheyenne. There is, therefore, a substantial technology bank upon which to draw, should it be desired to develop a compound rotorcraft for a specific application in the future, and it is not recommended that NASA direct any additional research towards the compound configuration at this time.

Advancing Blade Concept (ABC) and Tilt Rotor

The panel recommended that the XH-59A ABC and XV-15 Tilt Rotor proof-of-concept aircraft continue their presently-funded evaluation programs. These will give systematically acquired flight test data which can be compared to the user needs stated in Table I. It was also suggested that a configuration study be conducted to define the suitability of each of the high-speed advanced rotorcraft configurations for the user mission applications brought out during this workshop. The results of this study could then be used to guide the selection of future research tasks.

Two areas where specific research tasks were recommended to reduce weight empty were the use of fly-by-wire controls and the application of composite materials to major structural elements such as the tilt rotor wing. The use of FBW controls also offers the possibility of introducing active and adaptive controls. Together, the FBW controls and composite materials should reduce the weight empty fraction of high-speed advanced rotorcraft to the same order of magnitude as that exhibited by today's conventional helicopters. Both of these research tasks were also recommended during other workshop sessions.

High-speed rotorcraft are very sensitive to drag. Studies should be conducted to identify those areas in each configuration where the drag reduction potential is the highest, and specific research should be directed at each. In most cases, the research results could be demonstrated in flight, using the NASA proof-of-concept aircraft.

The ABC and Tilt Rotor performance is improved by engines that can produce high power with low fuel consumption over a wide range of engine rpm. It was recommended that the Propulsion Session adopt developing the needed powerplant technology as one of their objectives. During the Controls Session, it was suggested that research be directed towards reducing the empennage size and that entirely different empennage configurations be investigated. This recommendation was endorsed.

The rotor blades on the XV-15 were designed in the 1960's and represent the level of technology available about 15 years ago. There is now a NASA program to design, fabricate and flight test advanced technology blades for the XV-15. These new blades are expected to enhance the XV-15 performance in several aspects directly related to the rotorcraft user needs expressed at this workshop as indicated in Table III. The applicability of XV-15 tests with these new blades to most of the user needs indicates that their development is a highly pertinent technology program in support of a potential commercial tilt rotor and, as a result, it was highly endorsed.

TABLE III

USER NEEDS AFFECTED BY TILT ROTOR
ADVANCED TECHNOLOGY BLADES

<u>User Needs</u>	<u>Advanced Technology Blades</u>
<u>FIRST PRIORITY</u>	
Safety	X
OEI TO	X
Reliability	X
Noise	X
Speed	X
<u>SECOND PRIORITY</u>	
Range	X
Fuel Efficiency	X
Protected Tail Rotor	NA
Flexibility	X
Ground Disturbance	-
Large Size	NA
<u>THIRD PRIORITY</u>	
Crashworthiness	-
Compact	NA
Agility	X
Load Handling	NA

X = will affect user need

NA = not applicable

Lastly, there is an acknowledged increase in technical risk associated with advanced rotorcraft configurations as size is increased substantially beyond that already proven in flight test. Experience has shown that as gross weights are increased beyond about two to three times those representative of the existing technology base, dynamic component and structural frequency placements and relationships are of necessity altered.

Since a number of commercial users stated a desire for larger size advanced rotorcraft, it was recommended that NASA sponsor a design study of advanced rotorcraft components to determine the influence of size, and that consideration be given to the fabrication and test of full-scale components in the NASA-Ames 80 x 120 foot wind tunnel.

A number of flight test experiments were recommended as a result of the Tilt Rotor Workshop conducted just prior to this workshop. These recommendations are given in Volume VII of this report, and it is suggested that they be added to the XV-15 flight test program.

X-wing

The X-wing is proceeding through a test program under DARPA funding. The panel concluded that, following the completion of these tests, the X-wing configuration should be reassessed. This configuration is considered of a longer term and higher risk than the others, and it was not recommended that any additional research be contemplated at this time.

Although it was recommended by the panel members that it might be desirable to reduce the number of high-speed rotorcraft configurations under consideration, it was considered beyond the scope of this workshop to make such a recommendation. Furthermore, it was recognized that such a configuration selection would be

heavily dependent upon the specific application in question. Therefore, no attempt was made to assess the relative merits of the different high-speed rotorcraft configurations.

Since this workshop was commercially oriented, the issue was raised of how an advanced rotorcraft configuration could be certificated by the FAA. While there is an FAR Part-XX which was published in 1968, it does not reflect the present FAR's or current advanced rotorcraft technology. There is now an opportunity for NASA-FAA collaboration during the flight tests of the XV-15 to provide a data base against which the FAA could develop advanced rotorcraft certification criteria. Although these criteria would of necessity be preliminary, they would constitute valuable design guides for the use of industry should a commercial high-speed rotorcraft development be launched.

Summary

It was concluded that NASA should:

- (1) Conduct more aggressive, technically sound research directed at the practicable operation of a helicopter using a rotor in the propulsive mode at speeds exceeding 200 knots.
- (2) Complete the systematic flight research underway with the XH-59A and XV-15 aircraft.
- (3) Actively pursue those additional research tasks which have a high payoff in terms of meeting the user needs expressed in this workshop. These include the advanced technology rotor blades for the Tilt Rotor and those research tasks shown in Table II which have a broad application to the high-speed rotorcraft configurations found through design studies to offer the most promise for future commercial applications.

The compound has a large data base and should not be pursued, while the X-wing is currently being funded by DARPA and should be reassessed at the completion of that program.

LARGE ROTORCRAFT CONFIGURATIONS PANEL

The members of this panel were:

Gordon Fries	Subchairman
Peter Talbot	NASA
Mike Scully	Army
Tug Gustafson	Independent
Tom West	FAA
Ted Carter	Manufacturer
Bob Head	Manufacturer
John Schneider	Manufacturer
Frank Piasecki	Manufacturer
Hal Symes	User
Jim Lematta	User
Mike Evans	User

During the user presentations, strong support for large rotorcraft was indicated. The term "large rotorcraft" includes not only configurations specialized for heavy lift, but also cargo/transport configurations for internal transport as well as external lift, thereby greatly expanding their usefulness to commercial operators. Larger size was equated with reduced operating costs, a trend we have already seen develop in the fixed wing industry.

The two most serious problems now inhibiting the development of a large rotorcraft are the lack of a well-defined market and the high non-recurring costs involved. The high non-recurring costs to develop a large rotorcraft argues for mandatory participation by the military, and represents an area where civil user, military and industrial cooperation, perhaps through an HAA-NASA-industry initiative to combine large rotorcraft requirements, would prove very beneficial.

Four large rotorcraft configurations were considered: single-rotor, tip-driven; tandem-rotor, shaft-driven; multi-lift; and hybrid airship. The fact that the single-rotor, shaft-driven configuration was not addressed should not be construed as lack of interest in such a concept. Rather, it is believed that most of the research recommended for the tandem-rotor, shaft-driven configuration would be equally applicable to the single-rotor, shaft-driven configuration.

Single-Rotor, Tip-Driven

This configuration was flown many years ago in several experimental aircraft. While there have been many improvements in technology since, and the tip-driven rotor remains attractive from the point of view of reduced mechanical complexity, the weight fraction crossover compared to a shaft-driven configuration continues to lie at a very high gross weight. It was therefore concluded that no research should be devoted to the tip-driven rotor configuration, but that it should be reassessed through a design study to determine if, in the light of today's technology, it appears more promising than in the past.

Tandem-Rotor, Shaft-Driven

This configuration was endorsed during the commercial user presentations, and we are fortunate in having available the advanced technology components for such an aircraft from the Army XCH-62 program. The recently initiated test of the XCH-62 aft transmission is considered very worthwhile. The key step is not the transmission bench test, but rather the correlation with gear design methodology to develop the analytical tools needed to design mechanical drive systems for large rotorcraft. It was suggested that the center combiner transmission of the XCH-62 be added to this test program, since the components are available, provided it realizes a cost-effective contribution to rotorcraft transmission design technology. To expand the shaft-driven large rotorcraft technology base further, it is recommended that the benefits from a joint program with the Army to complete the XCH-62 for flight test be evaluated.

As rotorcraft become still larger, studies indicate it may be desirable to progress from two rotors to three or four rotors. In one concept, the two wing-propulsion systems from a conventional tilt rotor are combined into a quad-rotor configuration. No specific research tasks were recommended directed at this configuration, since the basic technology is under development in any event in support of the Tilt Rotor. This configuration, as well as the tandem-rotor and single-rotor, shaft-driven rotorcraft, should be included in any future NASA-sponsored design studies of large rotorcraft.

Multi-Lift

Several operators referred to the dilemma in which they find themselves when their helicopters have insufficient lift to carry one or two large pieces of equipment at, for example, a construction site. If it would be possible to link two of the helicopters together into a multi-lift aircraft, they then could transport these few pieces of outsized equipment. The panel recommended that a research task to develop the control laws for two helicopters linked together be developed on the NASA simulator. This could be followed by a flight demonstration of the multi-lift concept and master-slave control using two available helicopters.

Hybrid Airship

The hybrid airship is being developed as a prototype under a currently funded program. Following completion of this program, the panel recommended that the concept be reassessed against the user needs expressed at this workshop. While the hybrid airship is a highly specialized form of rotorcraft, it does offer an economical way to lift very large payloads over short distances, provided the past operational problems of lighter-than-air can be overcome.

Summary/Recommendations

It was concluded that NASA should pursue the technology for large rotorcraft in order to reduce the risks associated with future developments. Two areas of opportunity were identified: large shaft-driven helicopter technology and the

multi-lift concept. With regard to shaft-driven helicopters, the on-going program employing existing Army XCH-62 Heavy Lift Helicopter transmissions was endorsed, and it was recommended that consideration be given to expanding that effort. IN addition, benefits of a flight research program using the XCH-62 flight vehicle should be assessed. In the multi-lift concept, the feasibility demonstration of a master-slave control system should be pursued, and a flight demonstration using existing helicopters should be considered. Insofar as the remaining configurations are concerned, they should be reassessed when the design studies and information from the results of on-going programs become available. Notwithstanding the above recommendations, the lack of a clear market and the high costs involved in the development of large rotorcraft suggest that NASA should proceed cautiously.

COMMERCIAL-MILITARY COOPERATIVE OPPORTUNITIES

During the panel discussions, several opportunities for commercial-military cooperation were noted. A special presentation on this subject was made by Colonel John Zugschwert, who reported on the recommendations made by the helicopter commonality group (HELCOM). Among these recommendations are the possibility of creating a helicopter civil reserve air fleet (CRAF) similar to that of the airlines, the joint certification of new rotorcraft by unifying the military and FAA certification criteria wherever possible, and the opportunity to share development dollars for new rotorcraft. The latter recognizes the shortage of funding for new developments and the economic benefits to both the military and commercial users that would result from the larger number of helicopters that could be produced if the military and civil requirements could be unified. It was concluded that the commercial helicopter operators already have an organization, the HAA, through which they can follow up the recommendation pertaining to the CRAF. The other HELCOM recommendations will require joint DOD-FAA-industry action.

NASA ROTORCRAFT TECHNOLOGY

By

William Snyder
NASA Ames Research Center

I. EVOLUTION OF NASA ROLE IN ROTORCRAFT OUTLINE

- HISTORY
- CONTRIBUTIONS
- FUNDING
- ORGANIZATION
- FACILITIES
- AREAS OF EMPHASIS

ROTORCRAFT EVOLUTION

1940-1950	1950-1970	1970-PRESENT	PRESENT	FUTURE
MAJOR TRENDS				
<ul style="list-style-type: none"> • FIRST FLIGHT 	<ul style="list-style-type: none"> • TURBINIZED 	<ul style="list-style-type: none"> • TOTAL ARMY COMMITMENT 	<ul style="list-style-type: none"> • CIVIL USE ACCELERATES 	<ul style="list-style-type: none"> • STRONG FOREIGN COMPETITION
<ul style="list-style-type: none"> • MILITARY USE INITIATED 	<ul style="list-style-type: none"> • INCREASED USE IN KOREA 	<ul style="list-style-type: none"> • NASA ARMY LABS 	<ul style="list-style-type: none"> • FOREIGN INDUSTRY AGGRESSIVE 	<ul style="list-style-type: none"> • CONTINUED CIVIL NEED GROWTH
	<ul style="list-style-type: none"> • CIVIL USE STARTS 	<ul style="list-style-type: none"> • CIVIL USE GROWS 	<ul style="list-style-type: none"> • MILITARY DESIGNS PRESSED UTTAS AAH 	<ul style="list-style-type: none"> • NEW CIVIL AND MILITARY DESIGNS REQ'D
STATE OF TECHNOLOGY				
<ul style="list-style-type: none"> • TECHNOLOGY BASED ON AUTOGYRO AND FIXED WING 	<ul style="list-style-type: none"> • AVAILABLE TECHNOLOGY PRESSED BY INCREASING MISSION REQUIREMENTS 	<ul style="list-style-type: none"> • TECHNOLOGY DEVELOPED ON AD HOC BASIS BY INDUSTRY IR&D AND SR&T 	<ul style="list-style-type: none"> • TECHNOLOGY RESERVOIR EXPENDED ON NEW MILITARY AND CIVIL DESIGNS IN U.S. 	<ul style="list-style-type: none"> • NEED TO TIE NASA R&T TO INDUSTRY APPLICATION
<ul style="list-style-type: none"> • NACA PLAYS KEY ROLE 	<ul style="list-style-type: none"> • NACA/NASA RESPONSE TO NEEDS SLOWS 	<ul style="list-style-type: none"> • NASA FUNDS FOR RSRA AND TRRA 	<ul style="list-style-type: none"> • FOREIGN TECHNOLOGY GROWING RAPIDLY 	<ul style="list-style-type: none"> • NASA FOCUS ON CIVIL TECHNOLOGY NEEDS AND MIL SUPPORT

NACA/NASA ROTORCRAFT MILESTONES

1934 — 1972

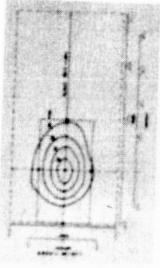
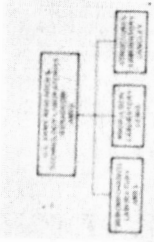
- 1934 — BASIC ROTOR ANALYSIS DOCUMENTED
- 1944 — FIRST RESEARCH HELICOPTER (YR-4B) FLIGHT TESTED
- 1947 — HELICOPTER TEST TOWER PUT INTO OPERATION
- 1948 — FLIGHT TESTS WITH HO3S-1 PROVIDED HANDLING QUALITIES CRITERIA
- 1954 — FIRST ROTARY-WING AIRCRAFT TESTED IN 40- BY 80-FOOT WIND TUNNEL (XV-1)
- 1958 — INITIAL FLIGHT TEST OF XV-3
- 1959 — STANDARD ROTOR PERFORMANCE CHART PUBLISHED
- 1965 — DESIGN CHARTS FOR HANDLING QUALITIES PUBLISHED
- 1965 — ARMY AERONAUTICAL RESEARCH LABORATORY ESTABLISHED AT AMES
- 1970 — JOINT ARMY LABORATORIES ESTABLISHED AT THREE NASA CENTERS
- 1971 — JOINT ARMY/NASA DEVELOPMENT OF TRRA & RSRA INITIATED
- 1972 — PARTICIPATED IN T-700 ENGINE MECHANICAL COMPONENTS DEVELOPMENT
- 1972 — FIRST AUTOMATIC APPROACH TO TOUCHDOWN DEMONSTRATED

NACA/NASA ROTORCRAFT MILESTONES

1972 — 1980

- 1973 — FIRST ROTORCRAFT SIMULATION ON FSAA (TILT ROTOR) ACCOMPLISHED
- 1973 — LASER VELOCIMETER USED TO MEASURE ROTOR FLOW FIELD
(7- BY 10-FOOT WIND TUNNEL)
- 1974 — AIRCRAFT NOISE REDUCTION LABORATORY COMPLETED
- 1974 — DEVELOPED AN IMPROVED TECHNIQUE ON MULTIPLANE BALANCING
ON ENGINE ROTORS (T-55, T-700, T-53)
- 1976 — AMES NAMED LEAD CENTER FOR HELICOPTER RESEARCH AND TECHNOLOGY
- 1976 — IMPACT DYNAMIC RESEARCH FACILITY USED IN TEST CH-47 FUSELAGE
- 1977 — FIRST HELICOPTER NOISE PREDICTION PROGRAM (ANOPP) DEVELOPED
- 1978 — FIRST FLIGHT AND DELIVERY OF TRRA ACCOMPLISHED
- 1978 — ROTORCRAFT TASK FORCE REPORT ISSUED
- 1979 — FIRST FULL CONVERSION WITH TRRA ACCOMPLISHED
- 1980 — VERTICAL MOTION SIMULATOR MADE OPERATIONAL
- 1980 — NASA ROTORCRAFT PROGRAM AUGMENTED BY CONGRESS
- 1980 — TRRA EXCEEDS 300 knots

ARMY LABORATORIES
AT THREE NASA
CENTERS

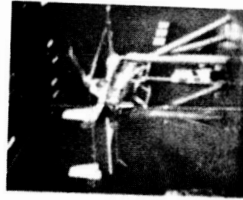


MAIN ROTOR
TRANSMISSION
DEVELOPMENT

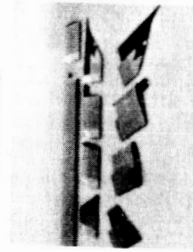


SIGNIFICANT NACA/NASA CONTRIBUTIONS TO ROTORCRAFT PROGRESS

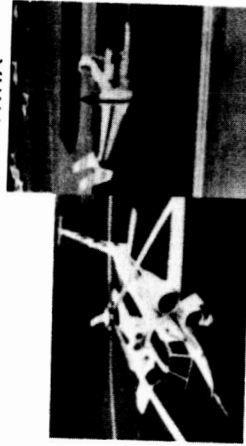
XV-1 TESTED IN
40 X 80



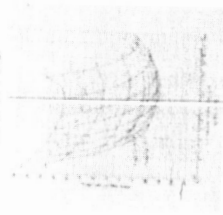
ROTOR BLADE TIP
STUDIES



INITIAL FLIGHT TESTS OF
TRRA



STANDARD ROTOR
PERFORMANCE
CHARTS



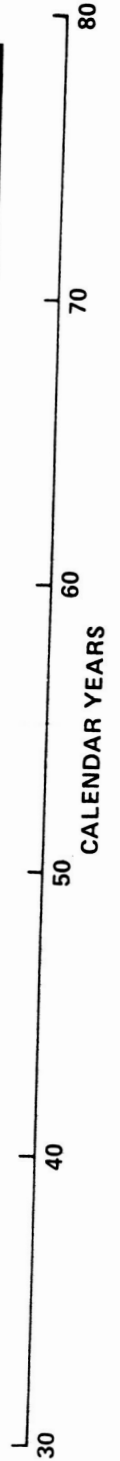
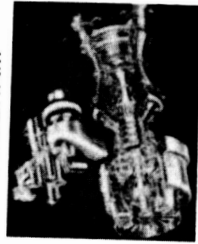
BASIC ROTOR
ANALYSIS



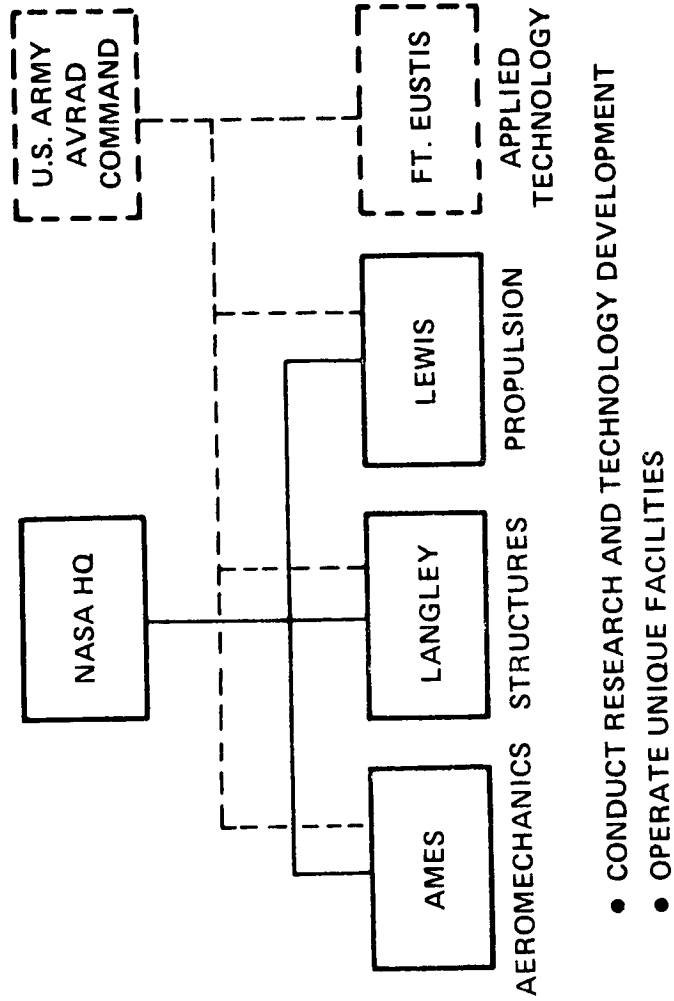
FLIGHT SIMULATION
OF ROTORCRAFT



T-700 ENGINE
DEMONSTRATION
PROGRAM



NASA ORGANIZATION OF ROTORCRAFT EFFORT



NASA TRADITIONAL ROLE IN ROTORCRAFT R&D

PROVIDE:

FACILITIES

- WIND TUNNELS
- SIMULATORS
- SPECIALIZED TEST RIGS

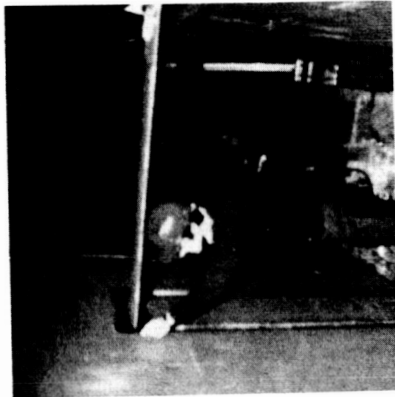
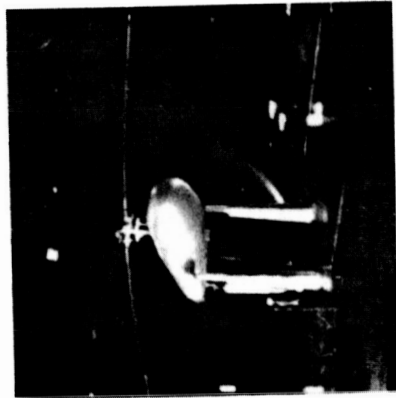
ANALYTICAL CAPABILITY

- LARGE COMPUTERS
- SOFTWARE DEVELOPMENT
- SPECIALIZED COMPUTER DEVELOPMENT

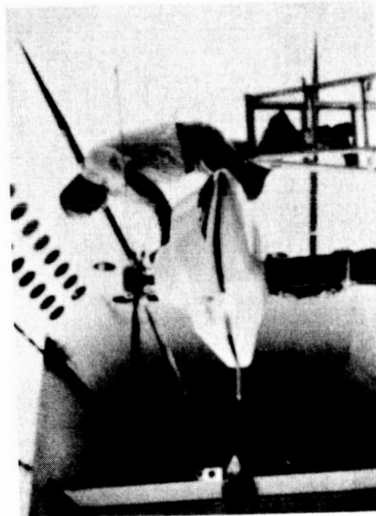
RESEARCH AIRCRAFT/FLIGHT TEST CAPABILITIES

- FLIGHT RESEARCH FACILITIES
- CONVENTIONAL HELICOPTER TEST BEDS
- SPECIALIZED RESEARCH AIRCRAFT
- SPECIFIC CONFIGURATION RESEARCH AIRCRAFT

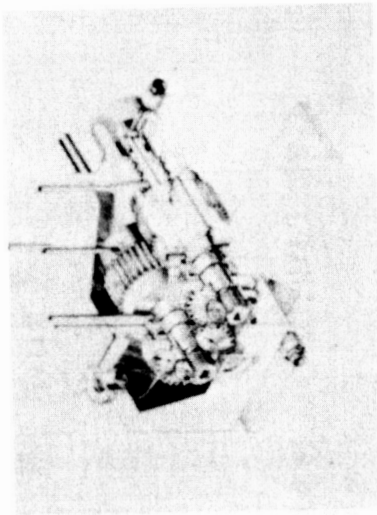
ROTORCRAFT DIRECT MANPOWER RESOURCES
FY 80



AMES
189 DIRECT MANPOWER



LANGLEY
38 DIRECT MANPOWER



LEWIS
42 DIRECT MANPOWER

TOTAL: 277 DIRECT MANPOWER

NASA FACILITIES WITH CAPABILITY FOR ROTORCRAFT RESEARCH AND TECHNOLOGY

TOTAL 1980 REPLACEMENT VALUE \$780M

AMES GROUND-BASED (1980 REPLACEMENT VALUE \$300M)

40- BY 80-FOOT WIND TUNNEL
80- BY 120-FOOT WIND TUNNEL
12-FOOT PRESSURE WIND TUNNEL
11- BY 11-FOOT TRANSONIC WIND TUNNEL
7- BY 10-FOOT WIND TUNNEL NO. 1
2- BY 2-FOOT TRANSONIC WIND TUNNEL
STATIC TEST FACILITY
FLIGHT SIMULATOR FOR ADVANCED AIRCRAFT
VERTICAL MOTION SIMULATOR
S19 FIXED BASE SIMULATOR
CROWS LANDING FLIGHT RESEARCH FACILITY
COMPUTER FACILITIES SUPPORTING ROTORCRAFT TECHNOLOGY

LANGLEY (1980 REPLACEMENT VALUE \$120M)

STRUCTURES/MATERIALS LABORATORIES
IMPACT DYNAMICS RESEARCH FACILITY
AIRCRAFT NOISE REDUCTION LABORATORY
VSTOL TUNNEL
TRANSONIC DYNAMICS TUNNEL
6- BY 28-INCH TRANSONIC TUNNEL

LEWIS (1980 REPLACEMENT VALUE \$160M)

ENGINE RESEARCH BUILDING COMPLEX
ENGINE COMPONENTS RESEARCH LABORATORY
MATERIALS AND STRESSES LABORATORY
9- BY 15-FOOT VSTOL WIND TUNNEL
ICING RESEARCH TUNNEL

NASA FACILITIES WITH CAPABILITY FOR ROTORCRAFT RESEARCH AND TECHNOLOGY (continued)

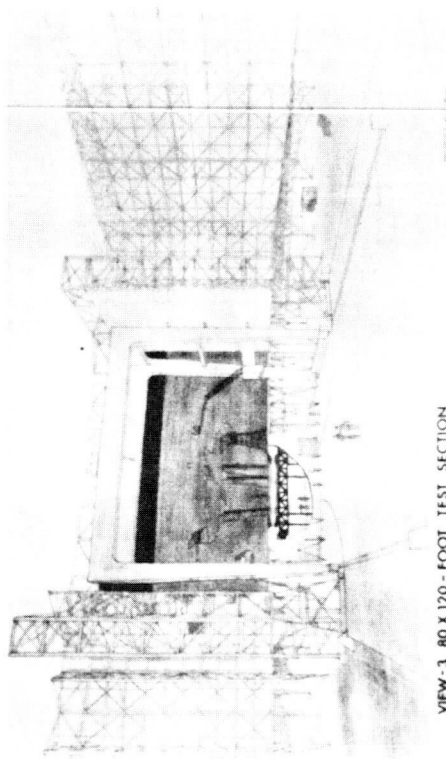
DRYDEN (1980 REPLACEMENT VALUE \$30M)

GROUND VIBRATION TEST EQUIPMENT
VTOL TEST STAND
MOMENT OF INERTIA TEST
FLIGHT LOADS RESEARCH FACILITY
NOISE MEASUREMENT SYSTEM
FLIGHT MONITOR AND TELEMETRY PROCESSING FACILITY

AMES RESEARCH AIRCRAFT (1980 REPLACEMENT VALUE \$170M)

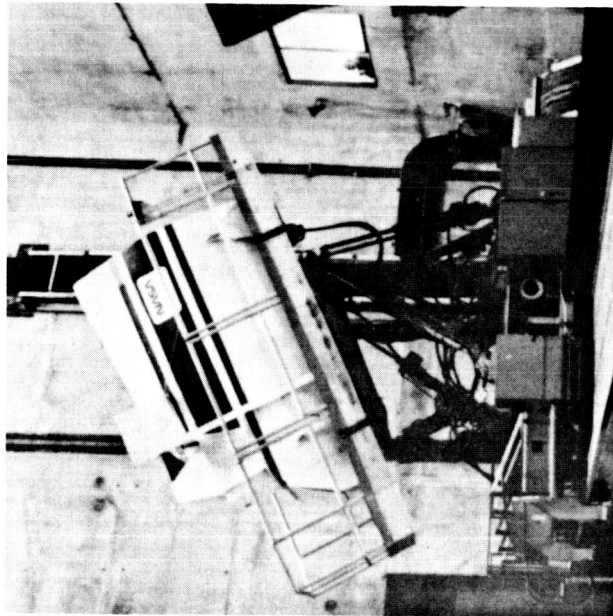
ROTOR SYSTEM RESEARCH AIRCRAFT
TILT ROTOR RESEARCH AIRCRAFT
ADVANCING BLADE CONCEPT
CH-47B VTOL APPROACH AND LANDING TECHNOLOGY
AH-1G COBRA
SH-3A SIKORSKY HELICOPTER
UH-1H IROQUOIS

CURRENT MAJOR FACILITY CONSTRUCTION/MODIFICATION WITH
ROTORCRAFT APPLICATION



VIEW-3, 80 X 120 - FOOT TEST SECTION

80- BY 120-FOOT
AND 40- BY 80-FOOT
WIND TUNNELS
COST: \$85M
COMPLETED: 1982



VERTICAL MOTION SIMULATOR
AND RELATED SYSTEMS
COST: \$11M (NASA ONLY)
COMPLETED: 1980

EVOLUTION OF AREAS OF EMPHASIS IN ROTORCRAFT PROGRAM

PAST:

EMPHASIS WAS HEAVILY ON AERODYNAMICS, ROTOR DYNAMICS,
AND FLIGHT DYNAMICS

ONGOING (CURRENT):

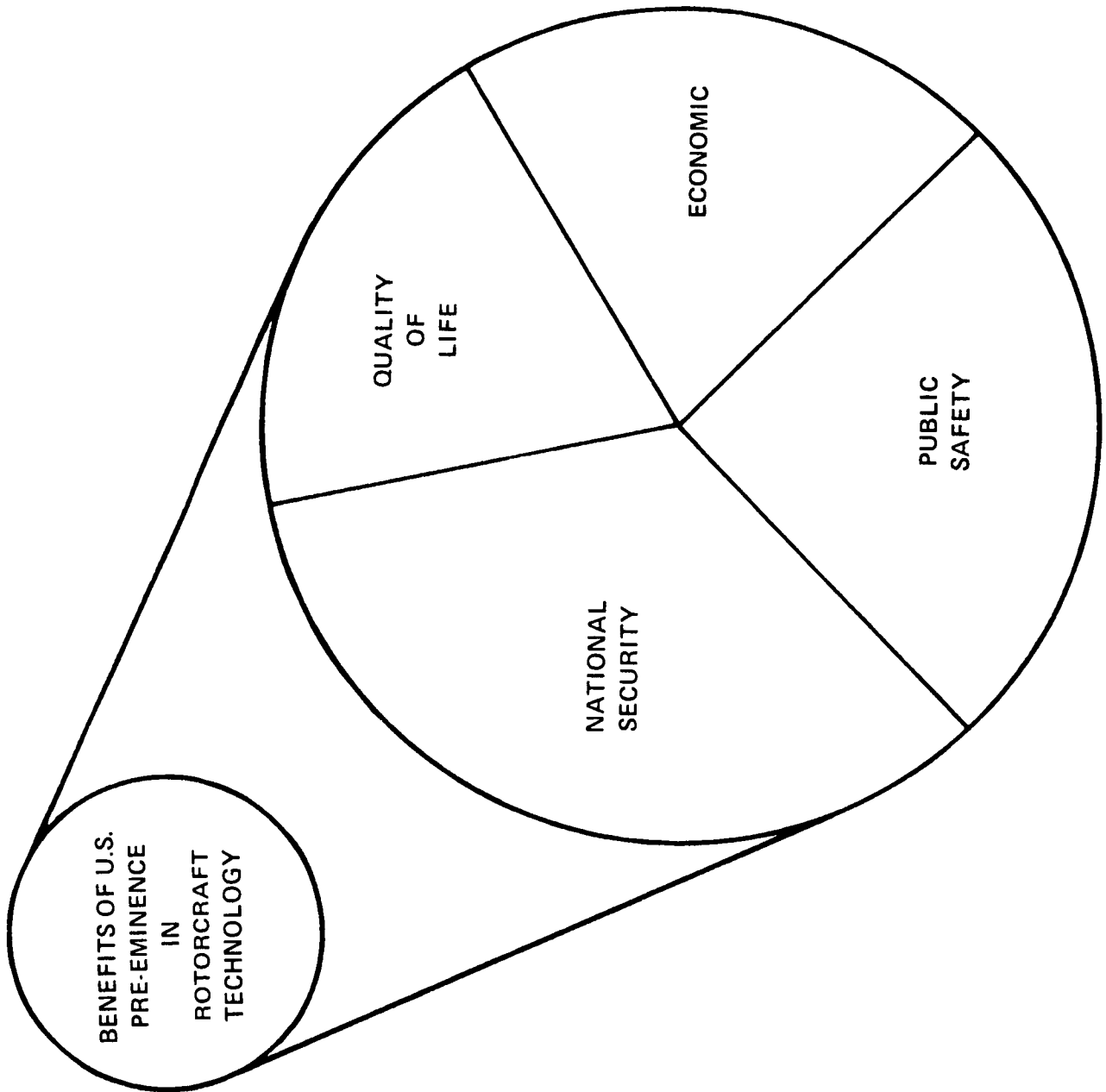
EMPHASIS IS PRIMARILY ON AEROACOUSTICS, VIBRATION REDUCTION,
AND AVIONICS/FLIGHT CONTROLS/HUMAN FACTORS WITH INCREASING
EMPHASIS ON PROPULSION SYSTEMS AND HIGH SPEED VEHICLES

FUTURE (AUGMENTED PROGRAM):

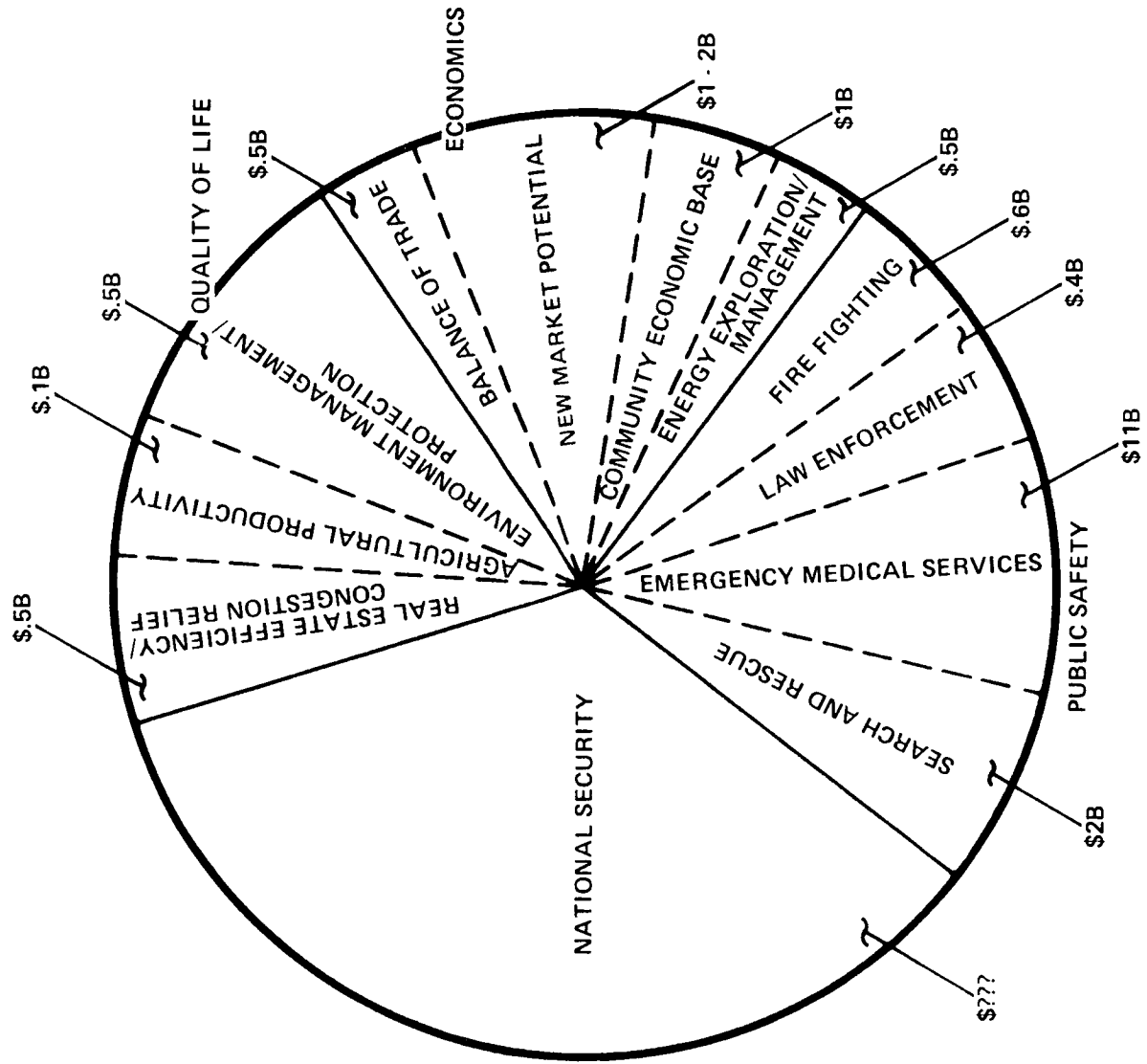
EMPHASIS WILL CONTINUE IN AEROACOUSTICS, VIBRATION, AND
AVIONICS/FLIGHT CONTROLS/HUMAN FACTORS BUT MAIN EMPHASIS
WILL BE SHARED WITH ADVANCED VEHICLE CONFIGURATION RESEARCH,
ADVANCED PROPULSION SYSTEMS RESEARCH AND ADVANCED
COMPOSITE MATERIALS TECHNOLOGY

II. UPDATE OF ADVANCED ROTORCRAFT TECHNOLOGY TASK FORCE REPORT OUTLINE

- BENEFITS/RATIONALE
- TASK FORCE REPORT RECOMMENDATIONS
- PRESENT STATUS
- SUMMARY OF 5 YEAR PLAN FY82-86



SUMMARY
ESTIMATES OF POTENTIAL ANNUAL ECONOMIC
BENEFITS OF ADVANCED ROTORCRAFT TECHNOLOGY



TOTAL POTENTIAL ANNUAL BENEFIT

\$19.1 BILLION + \$ NATIONAL SECURITY

WHY INCREASED ROTORCRAFT R&D?

THE PUBLIC BENEFITS

- 800,000 LIVES SAVED BY U.S. HELICOPTERS
- ESSENTIAL LINK IN DEVELOPING OFFSHORE OIL
- POTENTIAL FOR IMPROVING TRANSPORTATION SYSTEM
- IMPORTANT ELEMENT IN INCREASED FOOD PRODUCTION
- POTENTIAL FOR ADVANCED, LOW COST CONSTRUCTION METHODS

THE NATIONAL DEFENSE BENEFITS

- IMPROVED MOBILITY FOR DEPLOYMENT AND RESCUE
- IMPROVED CAPABILITY TO DEAL WITH TERRORIST ACTIVITIES WORLDWIDE

THE BALANCE OF TRADE BENEFITS

- KEEP U.S. INDUSTRY COMPETITIVE IN DOMESTIC AND 3RD WORLD MARKET

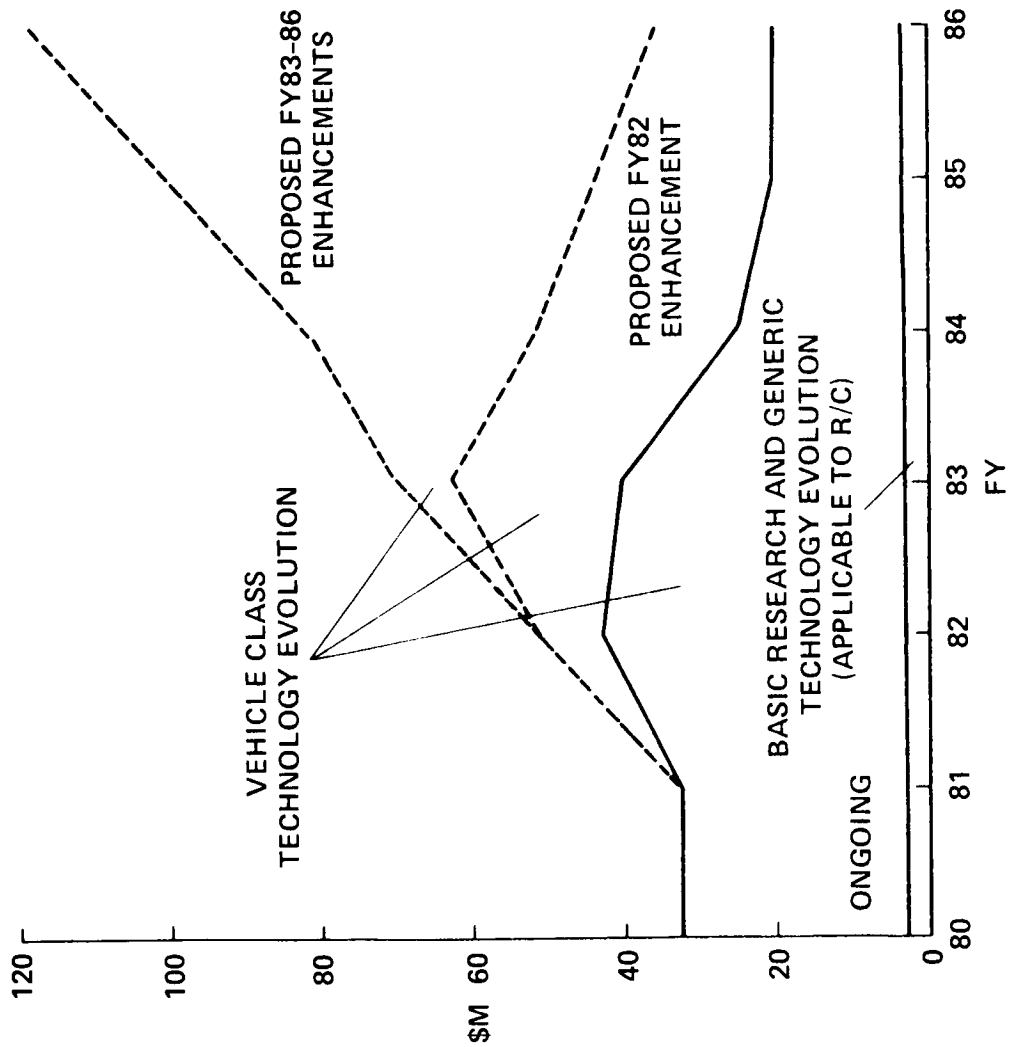
THE NEED FOR ADVANCED TECHNOLOGY IS GREAT

- SIGNIFICANT PROBLEMS EXIST
- MAJOR IMPROVEMENTS (25-50%) ARE STILL POSSIBLE
- TECHNICAL RISKS AND COMPLEXITY REQUIRE GOVERNMENT FACILITIES AND PARTICIPATION

PRESENT STATUS
ROTORCRAFT
 MAIN THRUSTS

BUDGET YEAR	PROPOSED	ACCOMPLISHED STARTS
FY'78	<ul style="list-style-type: none"> • RSRA OPERATIONS • HELICOPTER TRANSMISSIONS 	<ul style="list-style-type: none"> • RSRA OPERATIONS • HELICOPTER TRANSMISSIONS
FY'79	<ul style="list-style-type: none"> • ROTOR SYSTEMS INTEGRATION 	<ul style="list-style-type: none"> • ROTOR SYSTEMS INTEGRATION
FY'80	FIRST SUBMITTAL BASED ON TASK FORCE REPORT <ul style="list-style-type: none"> • DESIGN METHODOLOGY • FLIGHT CONTROL (ALL-WX) • PROPULSION 	<ul style="list-style-type: none"> • TRRA OPS (BASE ADJUST.) • AERO/ACOUSTICS • VIBRATION • ALL-WX • HIGH SPEED • PROPULSION
FY'81	<ul style="list-style-type: none"> • RC MODELING/ALL WX • VEHICLE CONFIG./SUBSYS. 	<ul style="list-style-type: none"> • RC MODELING/ALL-WX • AERO/ACOUSTICS • VIBRATION • ALL-WX
FY'82	<ul style="list-style-type: none"> • VEHICLE CONFIG./SUBSYS. <ul style="list-style-type: none"> • HIGH SPEED • PROPULSION 	<ul style="list-style-type: none"> • ?

PRESENT STATUS
ROTORCRAFT RESOURCES
 FY 80-86



ROTORCRAFT

5-YEAR PLAN SUMMARY

- TECHNOLOGY DEVELOPMENT FOR HIGH PRODUCTIVITY ROTORCRAFT TO MEET TRANSPORTATION, OFFSHORE OIL, AND CONSTRUCTION REQUIREMENTS.
- DEVELOPMENT OF ADVANCED COMPOSITE MATERIAL TECHNOLOGY FOR NEXT GENERATION OF AIRCRAFT.
- DEVELOPMENT OF CONVERTIBLE PROPULSION SYSTEM TECHNOLOGY FOR HIGH SPEED CONCEPTS.
- DEVELOPMENT OF INTEGRATED CONTROL SYSTEM TECHNOLOGY TO IMPROVE SAFETY, EFFICIENCY, RELIABILITY AND MISSION EFFECTIVENESS OF FUTURE VEHICLES.
- FURTHER DEVELOPMENT OF AEROACOUSTIC PROGRAM TO IMPROVE DESIGN METHODOLOGY FOR ROTOR/AIRFRAME AERODYNAMICS.

ROTORCRAFT 5-YEAR PLAN

FY'82-86

JUSTIFICATION

- **ESSENTIAL TO MILITARY FORCES**
 - RAPID DEPLOYMENT OF FORCES TO ANY THEATER
 - INCREASING NAVY/MARINE POTENTIAL
 - INCREASING NEED TO THWART TERRORIST ACTIVITIES
- **MAJOR BENEFITS FOR ALL CITIZENS FROM CIVIL APPLICATIONS**
 - PUBLIC SAFETY MISSIONS
 - FOREST AND AGRICULTURE MANAGEMENT
 - TRANSPORTATION OPPORTUNITIES/NEEDS
 - IMPROVED CONSTRUCTION METHODS
 - EMPLOYMENT
 - IMPROVED INDUSTRIAL PLANNING/DEVELOPMENT

BACKGROUND

- **ROTORCRAFT LAGS FIXED WING MATURITY BY 20 YEARS**
- **ENVIRONMENTAL AND ECONOMIC CONSTRAINTS**
- **AGGRESSIVE FOREIGN COMPETITION**
- **SOVIET BLOC INDUSTRY AND NEW MODELS (HINO-D, HALO)**
- **LIMITED DOD NEW DEVELOPMENT AND CIVIL SPIN-OFF OPPORTUNITIES**

ROTORCRAFT 5-YEAR PLAN

NEW PROGRAM THRUSTS

CRITICAL REQUIREMENTS	VEHICLE CONFIGURATIONS					CONVERTIBLE STRUCTURES		PROPULSION SYSTEMS		ROTOR/AIRFRAME INTEGRATION		INTEGRATED CONTROL SYSTEMS	
NOISE REDUCTION					○							●	
VIBRATION REDUCTION	○			●								●	
FLYING/RIDE QUALITY	●							●		●		●	
SAFETY					●		●		○			○	
R&M IMPROVEMENT					●		●		○				
ALL-WEATHER	○								●				
PRODUCTIVITY	●				○		●					●	
REDUCED FUEL					○		●					●	

● MAJOR IMPACT

○ MINOR IMPACT

ROTORCRAFT FIVE YEAR PLAN

PROGRAM ELEMENTS

PROGRAM THRUSTS	ENHANCEMENTS					
	FY 82	FY 83	FY 84	FY 85	FY 86	TOTAL \$ M
VEHICLE CONFIGURATIONS	HIGH SPEED FLIGHT TESTING, LARGE VEHICLE CONCEPTS					49.3
	HYBRID AIRSHIP					24.0
	LARGE VEHICLE FLIGHT TEST					40.0
	COMPOSITE AIRFRAME COMPONENTS					18.6
COMPOSITE STRUCTURES	COMPONENT TESTING					35.2
	SMALL ENGINE COMPONENTS					28.6
CONVERTIBLE PROPULSION SYSTEMS	POWER TRANSFER SYSTEMS					17.5
	ENGINE SUBSYSTEMS					24.1
	SYSTEMS INTEGRATION					69.1
	ACTIVE CONTROLS, ALL-WEATHER φ2					57.2
INTEGRATED CONTROL SYSTEMS	ALL-WEATHER φ3					24.2
	LARGE SCALE TESTING					49.4
ROTOR/AIRFRAME AERO INTEGRATION						
	\$6.0M (FY 1982)					

HIGH SPEED VEHICLE CONFIGURATIONS SUBSESSION

INTRODUCTION TO TILT ROTOR

(PRESENTATION BY ROD WERNICKE, BELL HELICOPTER TEXTRON)

The first four or five slides will bring those of you who missed out on the tilt rotor workshop and flight demonstration Tuesday up to speed with the rest of us. The first slide is the XV-15 tilt rotor in a hover. Think of the aircraft as turboprop aircraft with very large propellers. In the helicopter mode, it is very much like a tandem rotor helicopter. Most of the pilots who have flown it think it is a very pleasant machine in the hover mode. The real virtue of the machine is that in 12 seconds it can convert from the hover mode to the airplane mode (slides 2-4) and once in the airplane mode, accelerate to 300 knots at cruise altitude.

The productivity chart (slide 5) illustrates the tilt rotor concept potential compared to where we are today with our current helicopters. The weight empty, of course, of the tilt rotor is higher than that of a conventional helicopter. However, the tilt rotor achieves higher productivity with its speed and higher L/D. The tilt rotor makes up for the additional weight fraction in speed and in the reduced fuel consumption. The tilt rotor will provide rotorcraft like vertical transportation with about twice the range now available with current helicopters.

TECHNOLOGY ENHANCEMENTS

Recommendations for future NASA research to support the tilt rotor concept will be presented under four headings. Under the first heading are some enhancements to the current tilt rotor as it's flying today. When the program started the big risk, we thought, was the dynamic stability of the whirl mode flutter. The prime question was, did we really learn how to solve whirl mode flutter back in the 60's with all that wind tunnel testing. The XV-15 has shown that technology is in hand from that standpoint, and if there is any risk remaining, it's probably in the weight fraction, and do we really have the cruise efficiency that we claim we have?

Slide 6 shows the XV-15 in cutaway. It's a conventional sheet metal construction pretty much like we did back in the 60's or like the airplane people did back in the 60's, flush riveting, etc. The rotor itself is conventional late 1960's rotor technology, metal blades. The thing that might be a little bit different is it has a very thick wing in comparison to a fixed wing aircraft. This is due to the pylon stability requirements. The wing, for the same reason, is skinned with aluminum-honeycomb sandwich panel. But other than that, you are seeing an aircraft with essentially late 1960 technology.

There are three research tasks (slide 7) that NASA could help with in terms of weight reduction. This is a natural aircraft to employ fly-by-wire, fly-by-light. There has been some work done at NASA on a single channel, single axis, but for a vehicle like the tilt rotor, the real technology that is required is in the whole system architecture, the logic and so forth that goes with fly-by-wire.

Composite wing--in the mid 80's we will see composite structures maturing with the Army ACAP Program, and other similar developments. The wing of the XV-15 is unique in that it is designed for stiffness for dynamic reasons and has very high concentrated loads introduced at each wing tip. Handling concentrated loads is a difficult task with composites. Conceptual research is suggested.

Composite blades and currently available aerodynamic improvements offer potential weight reduction combined with substantial performance benefits. NASA has proposals in hand for composite blades for the XV-15. We want to document here that industry supports the decision to fund this research effort.

Another area of enhancement would be in performance (slide 8). Like any aircraft, the drag is important. Overall cruise efficiency is also tied closely to propeller efficiency. The XV-15 is flying with 1960 airfoils and what we could learn and determine back in the 60's about designing a combination propeller and rotor. The proposed composite blades as already noted, apply the best available advanced technology. In addition, XV-15 drag reduction should be a near term objective of the research flight test program.

OPERATIONAL CHARACTERISTICS

A little bit about operational characteristics (slide 9)--some of these things that I am going to address can be done with the aircraft itself and NASA is already planning to do many of them. Other items would more appropriately be done in the laboratory or in the simulator.

Investigation of deck edge effects can be conducted with an XV-15. Both military and commercial operators have voiced concern that there might be performance or handling qualities problems when the rotors extend beyond the landing deck edge. Limited evidence to date indicates this will not be the case, but this should be verified for the potential users. In the meeting yesterday, Mr. H. G. Thompson, Director of Operations for Air Logistics, offered help in conducting tilt rotor evaluations on an offshore platform. NASA should consider accepting his offer.

A second concern to operators (slide 10) is the helicopter mode maneuverability or agility. If there is a place that the tilt rotor would fall short from what we are used to with helicopters, it would be in the very low speed regime, 40 knots and below. This needs to be explored both with the aircraft and possibly by use of simulators.

Erosion and re-ingestion problems have given VTOL a bad image in the past. The tilt rotor has a unique flow field with the two side-by-side rotors. NASA is going to be quantifying very soon the dynamic pressure field underneath the rotors, but it is very important that in addition to that quantitative data that a qualitative exposure of the aircraft is undertaken; actually taking it into a dust environment and flying it over the water and letting operators really see what the tilt rotor's characteristics are in an operational sense. This is one of the things that shot down the XC-142. It is time now to identify the tilt rotor's erosion and re-ingestion characteristics.

It is debatable whether deicing should be on the V/STOL research list since it is a concern for all rotorcraft. It is included because any production tilt rotor will have deicing; it will probably be standard equipment. A blade deicing system that will work on a helicopter will also work on the tilt rotor and of course the airplane surfaces lend themselves to the classical airplane solution to deicing. Active controls are called out on the slide. Since fly-by-wire systems and active control systems are coming along, there is a good possibility that with a little bit of additional electronics; we can get deicing by exciting the blade modes. I feel very strongly that this should be pursued for all rotorcraft. However, after listening

to the discussions over the past several days I would change my recommendations and make them more general. NASA's business really should be in developing the testing and certification technology. The possibilities of scaling for icing research should be investigated.

We are anxious to see NASA explore and quantify STOL characteristics with the XV-15 too, and I am sure that they are going to do that.

NEXT GENERATION TILT ROTORS

Recommendations discussed to this point would support pursuing the tilt rotor concept as demonstrated by the XV-15. However, NASA should anticipate and nurture the broadening of the tilt rotor concept for future configurations.

Reviewing for a minute the tilt rotor origin and possible future--the XV-3 convertiplane (slide 11) was a relatively small rotorcraft with a low disc loading below 5 psf. The XV-15 (slide 12) operates at 13 psf. Slide 13 is an artist's concept of a next generation tilt rotor. Predesign studies and effectiveness analyses indicate disc loadings should be of the order of 18 psf or higher--possibly as high as 25 psf for the next generation tilt rotor.

There is a number of research tasks associated with going to higher disc loadings. For example, the conversion envelope (slide 14), is influenced by disc loading.

The XV-15 conversion envelope is about 60 to 80 knots wide. The pilot can stop at intermediate angles, such as 45° , in the envelope and slow down, speed up and maneuver. As the disc loading goes up, wing loading will by necessity have to go up also causing the left-hand boundary to shift to the right. We suspect that the rotor may suffer some also causing the right-hand boundary to shift to the left. This is just one of the areas that needs investigation regarding higher disc loading and is very amenable to simulator evaluation.

Continuing with research recommendations for the next generation--

The next two listed (slide 15) deal with aerodynamic enhancements for cruise flight. Winglets or sails on the tilt rotor nacelles could significantly increase the lift to drag ratio. Optimization of the tail configuration could further reduce drag. The XV-15 "H" tail has considerably more volume than is needed, particularly the vertical. Hopefully, NASA will experiment with removing some tail area from the existing aircraft. Additionally, optimization of future designs needs to be investigated.

The last two items listed are for the far out future. They may not really be the next generation but a generation after the next generation. But it's necessary to start research now to have speeds above 400 knots and tri or quad tilt rotors in 20 years.

The tri or quad tilt rotor (slide 16) is a natural evolution from today's tilt rotor for a high speed solution for heavy lift. The advantage over a conventional helicopter for carrying internal cargoes long distances is obvious. For carrying external cargo, the advantage would be in its long range and high speed capability to transit to remote job sites.

ULTIMATE USAGE

The last category of recommendations is entitled Ultimate Usage--that is a little bit of an awkward title but if I would say where the priority should be I would say it should be in this area that I am going to discuss now. If we can really build an advanced V/STOL machine--can the public use it (slide 17)? There has been a dream of a lot of us for years in the rotorcraft business that one day we would be able to provide a city center to city center scheduled transportation system. At one time it looked like it was going to be a reality using helicopters. I hope that the rest of you gentlemen here at the table would say: that as far as an aircraft to do that mission--we can have that aircraft in 10 years. But I am not so sure that the rest of the system--the airport facilities, the air traffic system will ever be in place unless an organization like NASA is challenged, and I mean a national challenge to define how that system should be put together. NASA put a man on the moon--that was a national challenge and they did it and if given a similar challenge to put together a transportation system we could have the aircraft and we could have the system in 10 years. I would like to suggest that we help NASA go out and solicit that assignment. If nothing else, at least write the spec for that system. We can build the aircraft but we don't know what the rest of the system looks like--we don't know whether we need a 30-passenger or 50-passenger. We don't know what the runway lengths are. If we are going to look at the cost effectiveness of the overall system, we have to know what it is going to cost to handle the people as well as the aircraft. There was quite a discussion last night on the user acceptance. I am suggesting that we challenge NASA to take on a much bigger obligation than we were talking about in the discussion last night.

NASA could take on the responsibility of identifying the characteristics of a V/STOL transportation system (slide 18)--stage lengths, runway sizes, etc. Will landings be made on roof tops? Possibly heliports could be put on top of existing freeways. For the tilt rotor aircraft, the freeway noise would probably mask the aircraft noise.

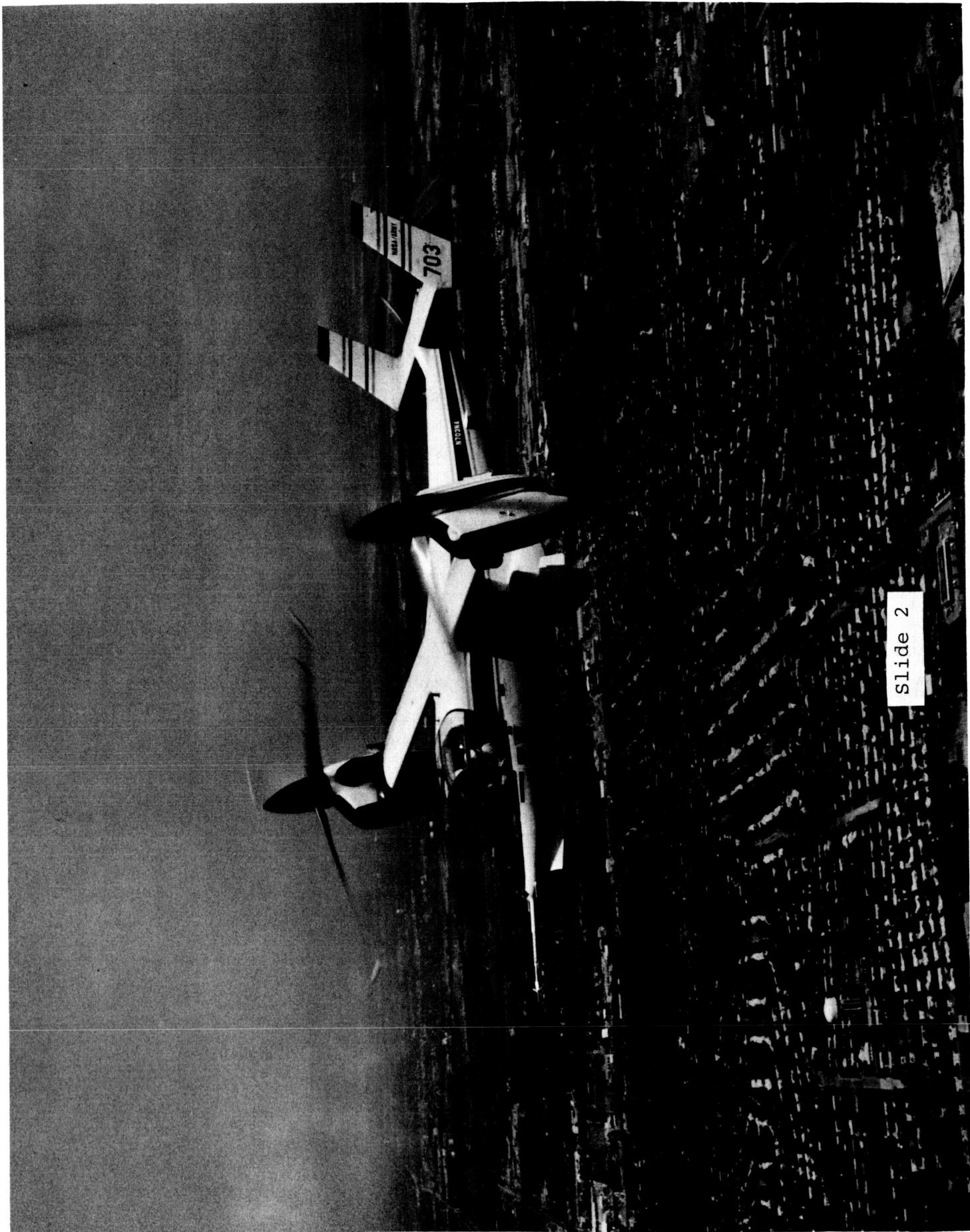
A final area that NASA could help in would be in the development of methodology and regulations for certification. Back in the 60's, there was a Part XX airworthiness regulation put together and I believe since 1970 there hasn't been any work done on it. If we were to go to certification tomorrow, we would probably use both Part 25 and Part 29.

There is a lot of interest in using simulators in the certification process. This is a fertile field for NASA's capabilities. The aircraft are coming and now is the time to start thinking of how they are going to be certificated. That concludes my comments. Thank you very much.

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

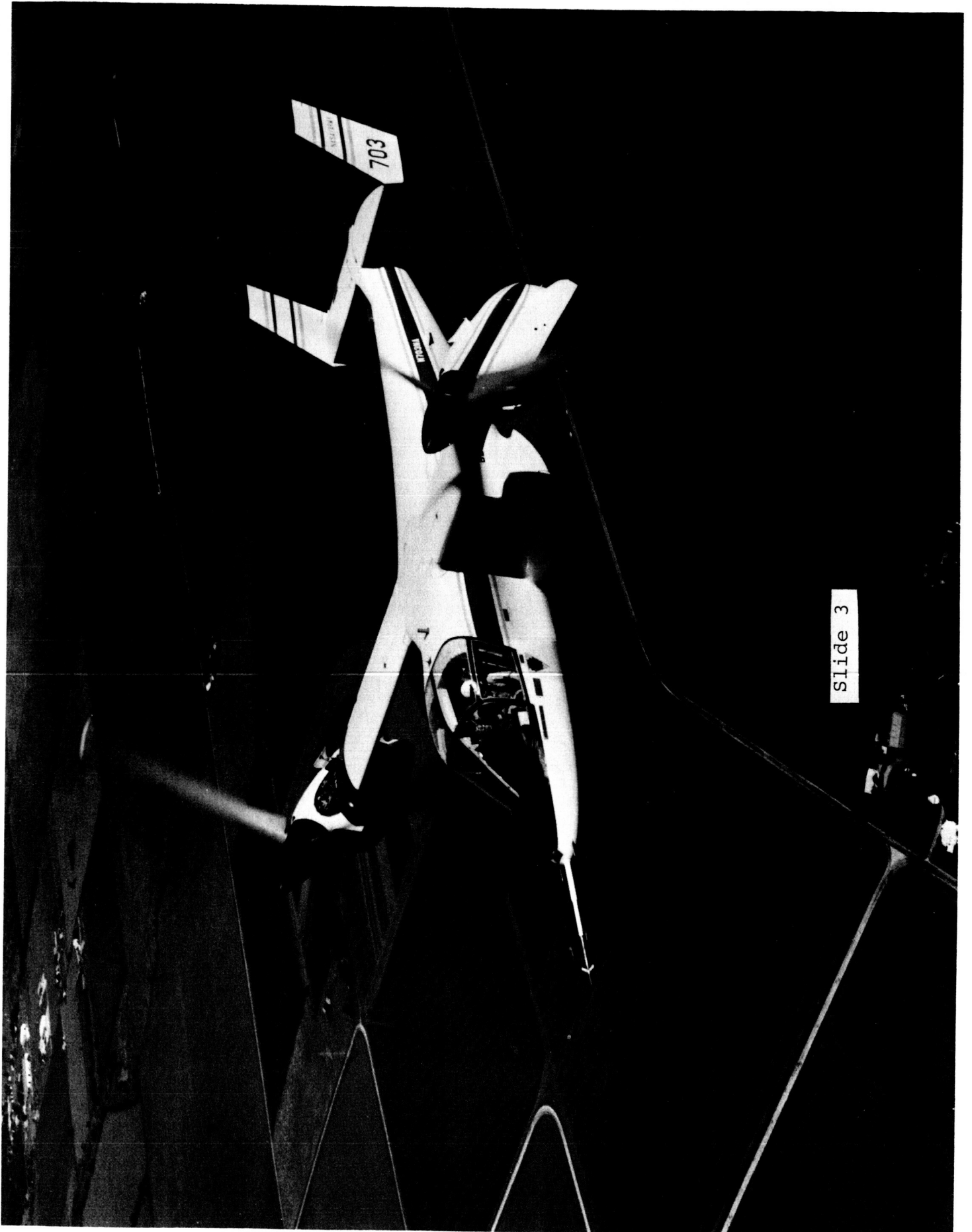


Slide 1



Slide 2

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH



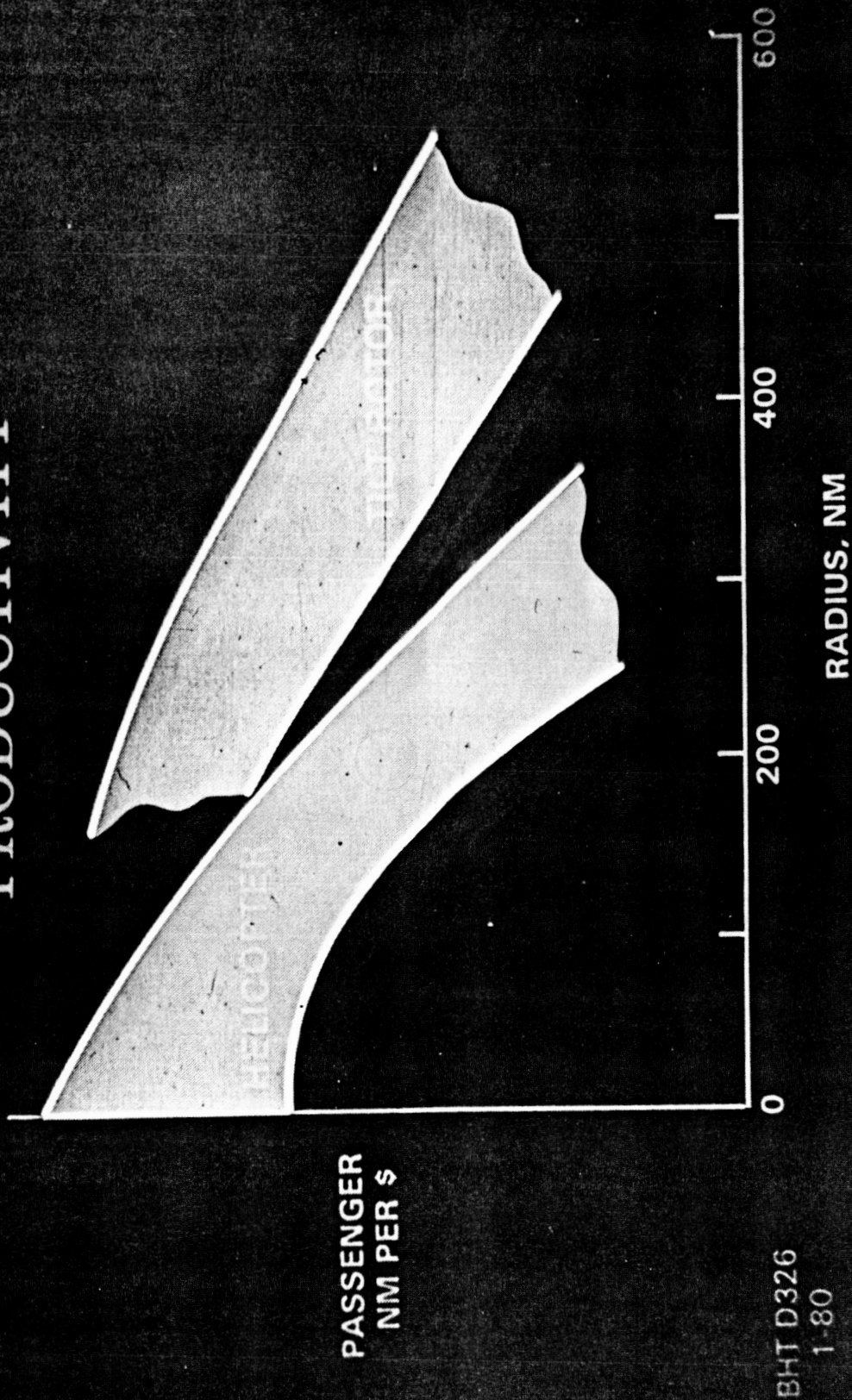
Slide 3



Slide 4

VI-54

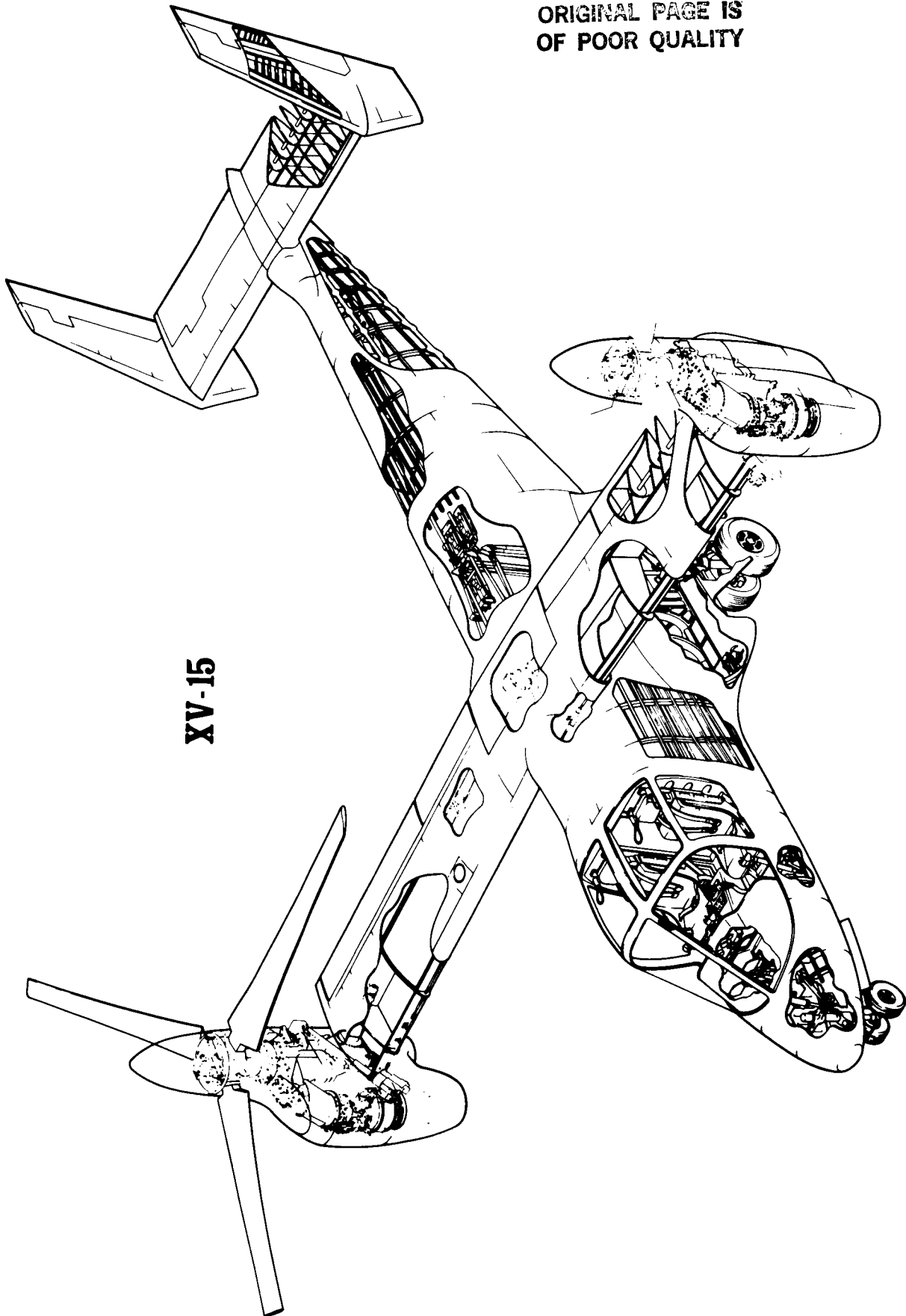
PRODUCTIVITY



BHT D326
1-80

Slide 5

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OF POOR QUALITY



XV-15

Slide 6

VI-56

304883

Bell Helicopter TEXTRON

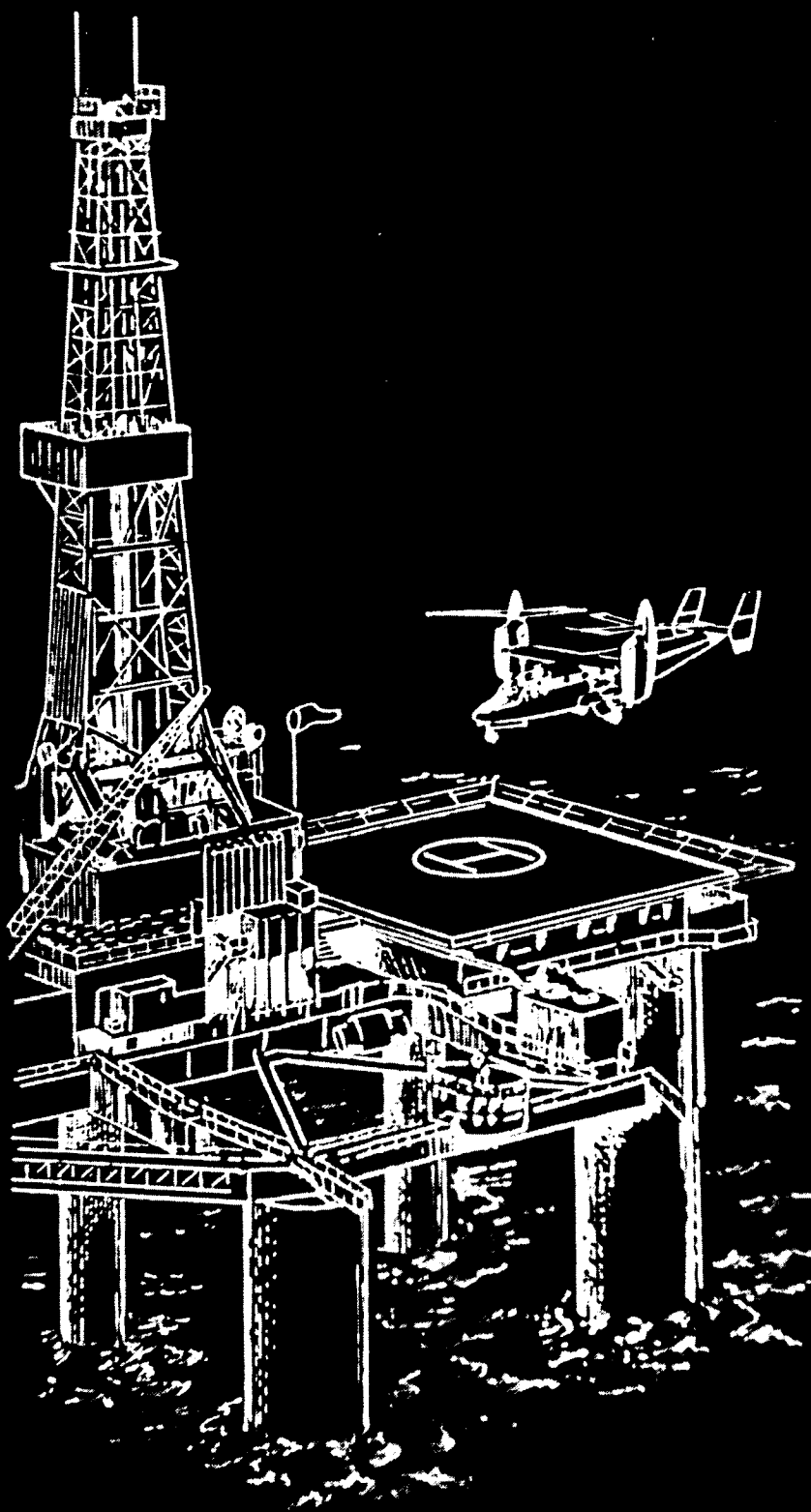
WEIGHT REDUCTION

- FLY-BY-LIGHT
- COMPOSITE WING
- COMPOSITE BLADES

Slide 7

PERFORMANCE ENHANCEMENT

- REDUCED DRAG: BETTER VEHICLE L/D'S
- INCREASED PROP-ROTOR EFFICIENCY



Slide 9

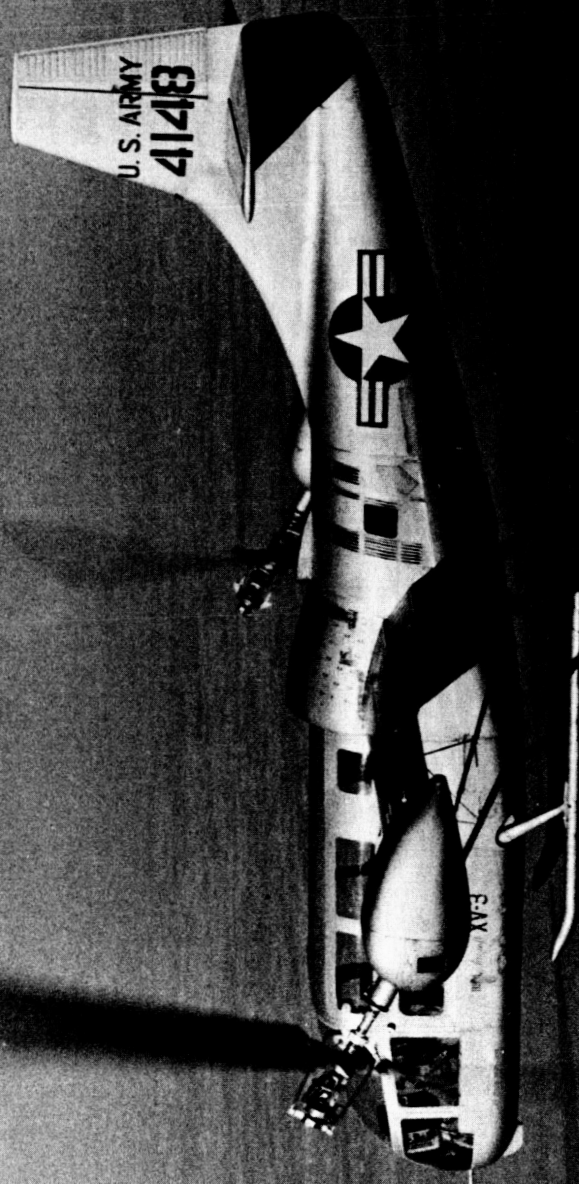
VI-59

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OPERATIONAL CHARACTERISTICS

- DECK EDGE EFFECTS
- HELICOPTER MODE MANEUVERABILITY
- EROSION-RE-INGESTION FLOW FIELD
- PROPROTOR DEICING WITH ACTIVE CONTROLS
- STOL

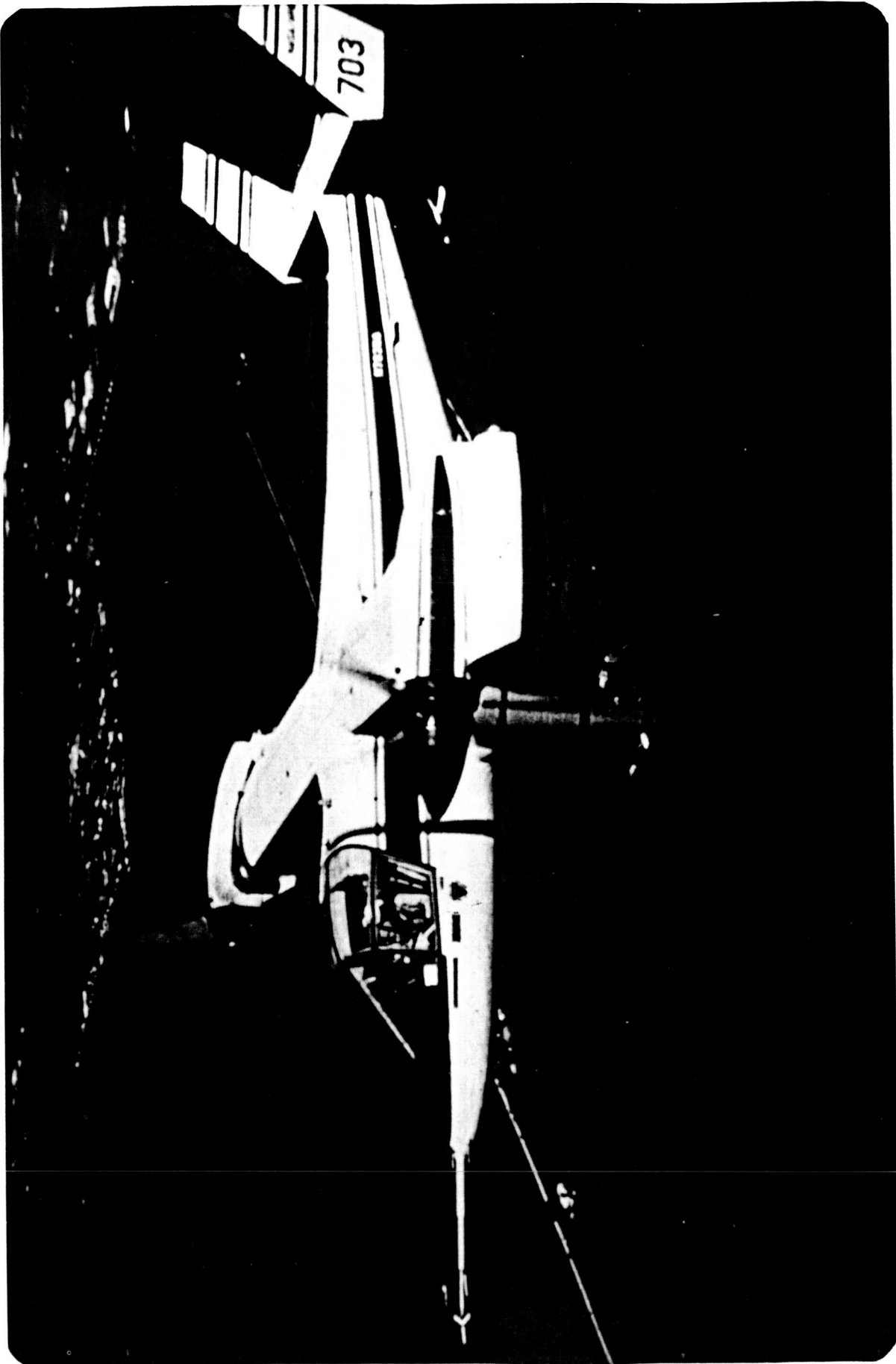
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Slide 11

VI-61

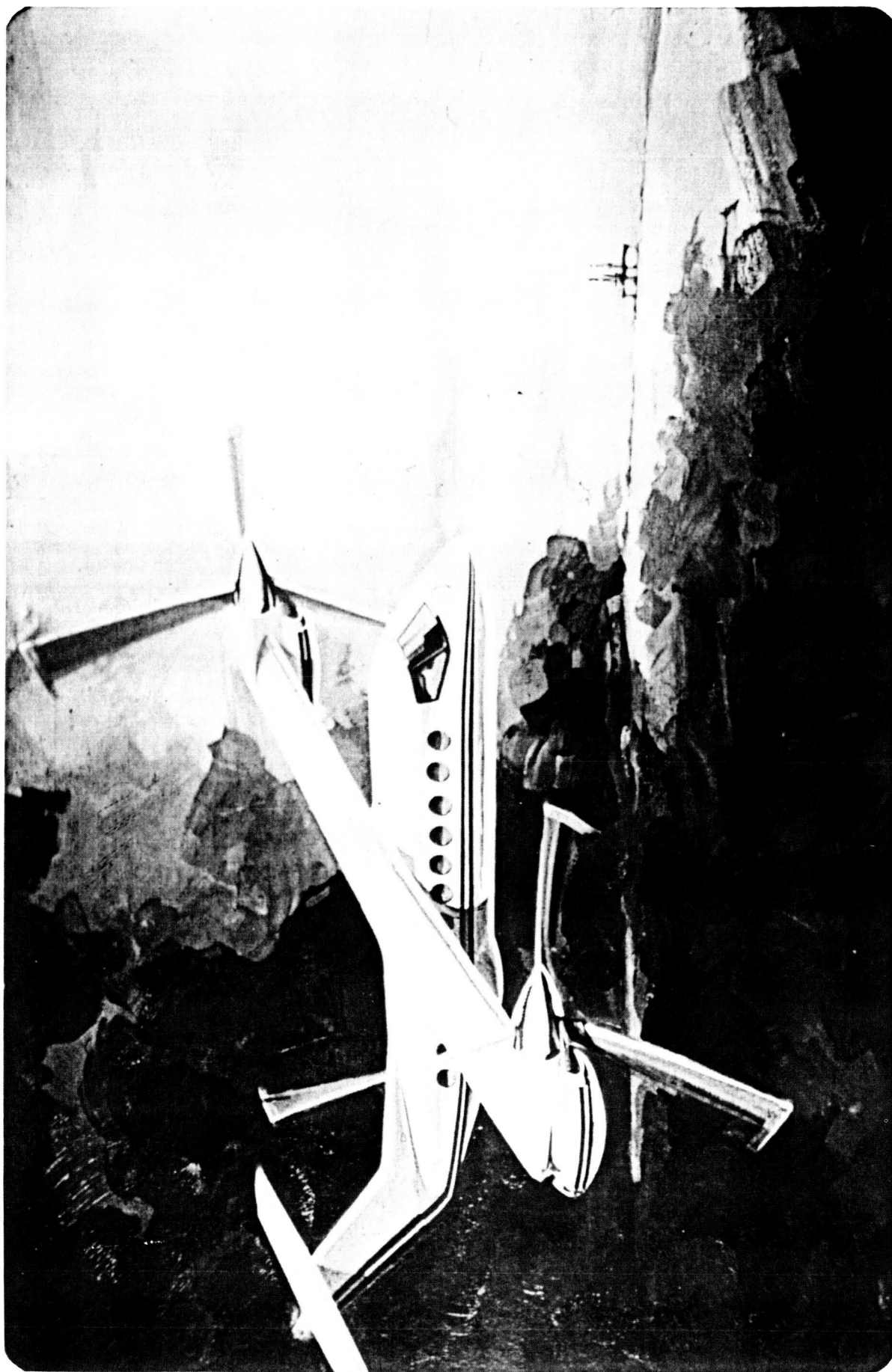
BELL HELICOPTER 225404
A TEXTRON COMPANY



Slide 12

VI-62

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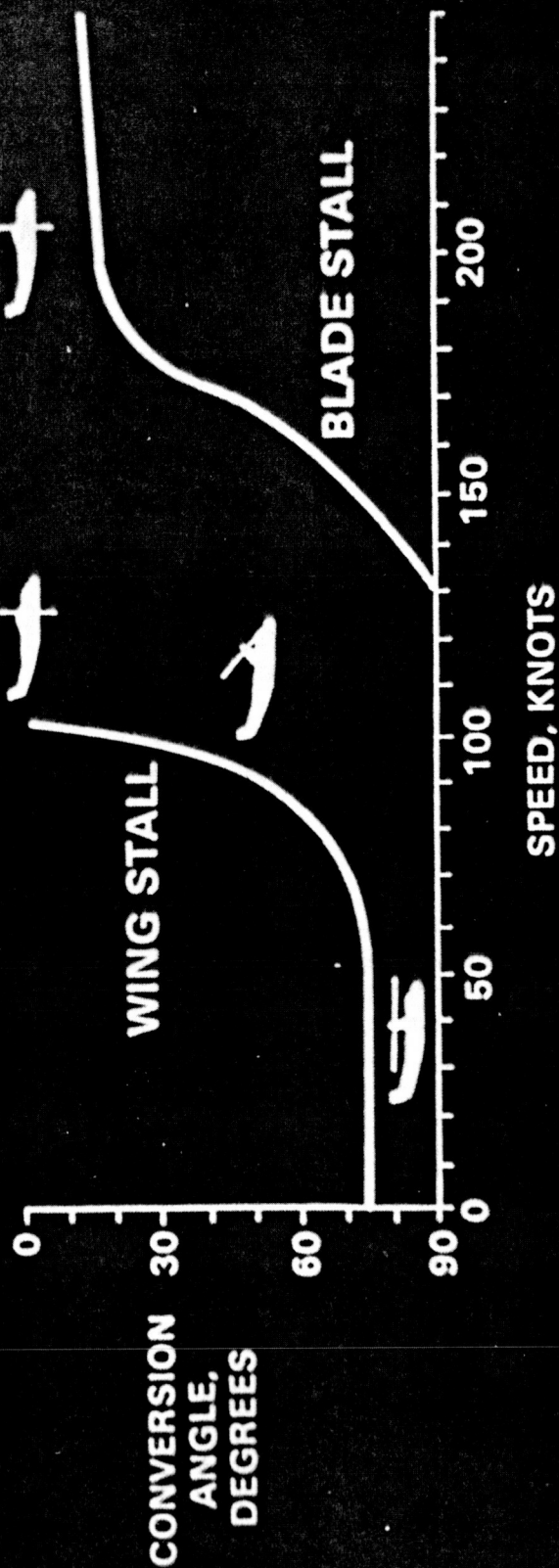


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VI-63

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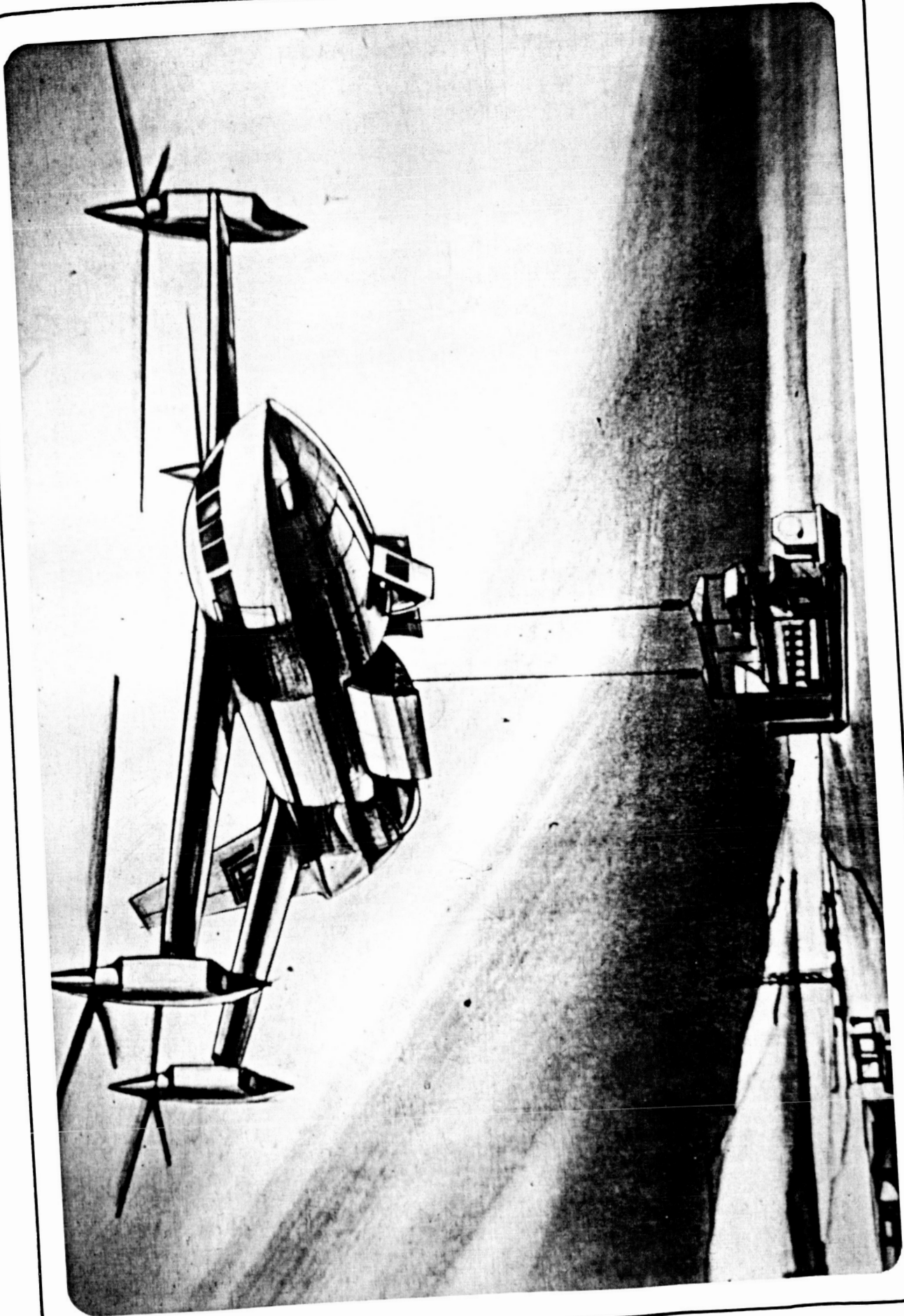
CONVERSION



BHT D326
1-80

NEXT GENERATION TILT ROTORS

- HIGHER DISC LOADING (CONVERSION CORRIDOR, S & C)
- WINGLETS
- ALTERNATE EMPENNAGE CONFIGURATIONS
- HIGHER SPEED, 400+ KNOTS
- TRI OR QUAD ROTORS



Slide 16

VI-66

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Slide 17

VI-67

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ULTIMATE USAGE

- 1990'S V/STOL TRANSPORTATION SYSTEM
 - STAGE LENGTHS
 - AIR SPACE: TERMINAL AND ENROUTE
 - LANDING FACILITIES
 - SIZE ?
 - ROOFTOP ?
 - ELEVATED ?
- FAA CERTIFICATION
 - UPDATE PART XX
 - USE OF SIMULATORS

THE X WING VTOL TECHNOLOGY NEEDS

By

Leo Kingston
Sikorsky Aircraft



PSD 341437

Figure 1 — Circulation Control X-Wing V/STOL Aircraft Concept

WHAT IS X-WING?

X-Wing is primarily a fixed wing aircraft with two pairs of wings. One pair of forward swept wings of 45° and one pair of 45° aft swept wings. This aircraft can operate in helicopter mode. This is accomplished by rotating these four wings in helicopter fashion. Each wing (blade) consists of a symmetrical section with rounded leading and trailing edges. By blowing tangentially at the trailing edge of each one, airfoil lift can be varied as a function of efflux momentum. Thus, cyclic variation in lift can be achieved without changing the geometric position of a blade. In the helo mode, no cyclic controls are required in the rotating system though collective pitch change may be required. In the fixed wing mode, as well as during part of the conversion, the reverse flow will convert the trailing edge to a leading edge and visa-versa. To address this problem, air can be blown from either the leading or trailing edge. This concept is not only unique, but it promises effective performance from hover to 500 knots in a very compact configuration.

This concept which was spear-headed by DTNSRDC was pursued by Lockheed who carried the effort of a 25 ft. rotor through a successful full-scale 40/80 wind tunnel program. It is now under contract with Boeing-Vertol, as well as Sikorsky Aircraft.

Great opportunities are usually accompanied by risk. There are two areas of risk identified; technical and viability.

The major technical risk will be in the area of conversion which provides a very challenging control requirement, as well as the ability to handle the high vibratory loads anticipated in an untreated aircraft.

The area of viability must assess the realistic empty weight fraction as well as the realistic drag in the fixed wing mode.

A great deal of work has been done by DTNSRDC, Lockheed, and Kaman, but much more should be done in the area of aero-mechanics, control, and propulsion to support such a novel and promising approach.

AEROMECHANICS

The library is very thin in the area of equivalent airfoil data (steady and unsteady.) Wing and body interaction will require a better understanding. Additional analytical modeling will be required.

DYNAMICS

Since blades operate from full RPM to fixed wing, tailoring will be required not only to operate in the extremes of these modes, but also to survive the transition as resonant regions must be transgressed. The opportunity of HH blowing must be investigated, not only as a desirable adjunct, but a necessary requirement.

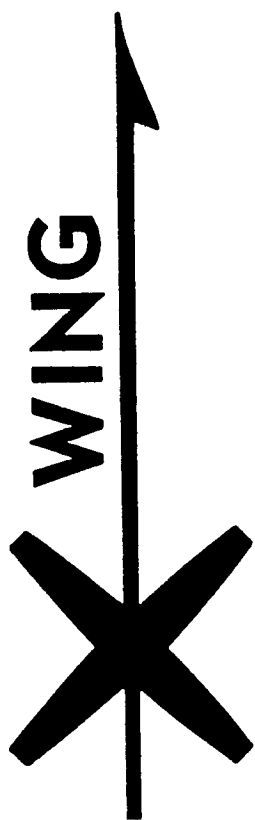
CONTROL

Control offers a variety of options to achieve its objective. The wing (blades) can change collective pitch which has a very different effect in the fixed wing mode than in the helo mode. Moments and lift variably can be accomplished by pneumatic control, and of course, vertical and horizontal surfaces can be used. While the technology of the latter is well understood, the following requires attention. The pneumatic distribution (valving, ducting, etc.):

A control algorithm which will allow real time procedures to direct a fly-by-light system must also integrate the demand of the powerplant.

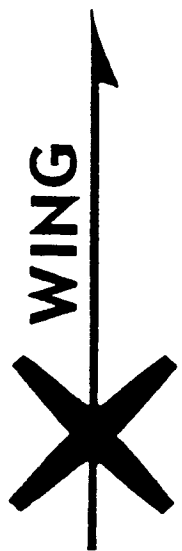
PROPULSION

Propulsion requirements are unique. The powerplant has to satisfy the needs of shaft power, compressor power, as well as serve a propulsion device. It can be seen that the fuel control will have to be far more sophisticated. The development of a compressor of high efficiency over a wide band of pressure ratio and mass flow will require some novel approaches. The fact that the X-mission requires only a very brief period of maximum power may offer weight savings approaches for limited life operation.



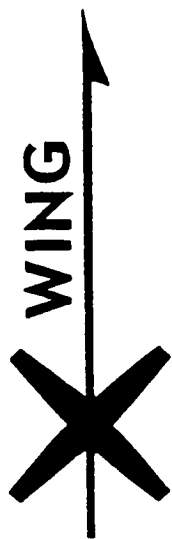
VI-74

A UNIQUE OPPORTUNITY



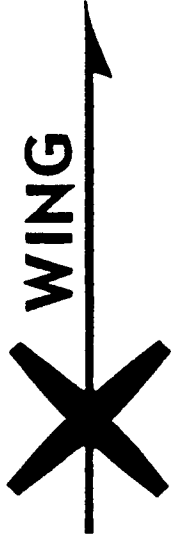
RISKS

- **CONVERSION**
- **PRODUCTIVITY**



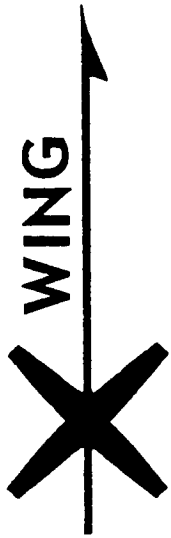
- **A Substantial Technology Data Base Has Already
Been Established**
 - DTNSRDC
 - LOCKHEED
 - KAMAN

- **Additional Research Still Required To Mature Concept**
 - Aerodynamics
 - Dynamics
 - Pneumodynamics
 - Control
 - Propulsion



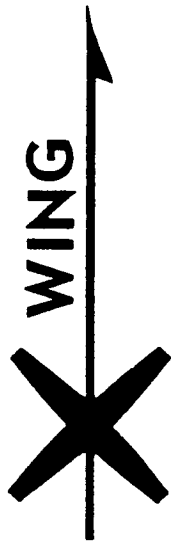
AERODYNAMICS

- **Advanced Circulation Control Airfoils**
 - **New Sections**
 - **Coanda Surface Geometry**
 - **Slot Optimization**
- **Unsteady Aerodynamics**
- **Wing/Body Interaction**
 - **Rotary Wing Mode - Proximity Effects**
 - **Fixed Wing Mode - Separation Effects**
- **Wake Geometry**
- **Rotor Aerodynamic Optimization**
- **Analytic Techniques**



DYNAMICS

- **Blade Aeroelastic Tailoring**
 - **Fixed Wing**
 - **Rotary Wing**
- **Coupling Effects**
- **Higher Harmonic Blowing Effects**
 - **Vibration Control**
 - **Structural Coupling**
- **RPM Variation**
 - **Resonant Effects**
 - **Damping Requirements**



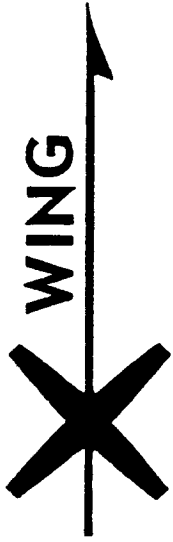
CONTROL

- **Pneumatic Controls**
 - **Valving**
 - **Number**
 - **Type**
 - **Distribution**
 - **Actuation**
 - **Control Algorithms**
 - **Higher Harmonic Control**
 - **Phase Shifts**
 - **Auto-Conversion**
- **Mechanical Controls**
- **Electronic Controls**
- **Integration**



PNEUMODYNAMICS

- **Duct Aerodynamics**
 - **Losses**
 - **Pressure Pulse Propagation**
 - **Air Path Resonance**
- **Slot Dynamics**
 - **Stiffness Criteria Vs Dynamic Response**
 - **Higher Harmonic Blowing**
- **Phase Angle Shifts**
 - **Ambient Conditions**
 - **RPM Variations**



PROPULSION

- **Requires Both Shaft Horsepower And Propulsive Thrust Simultaneously**
 - Convertible Engine
 - Conventional Turboshaft & Advanced Propulsors
- **Air Supply**
 - Broad Band Operation Without Sacrificing Efficiency
- **Air Management**
- **Short Duration Operation**
- **Power Distribution & Control**
 - Advanced Fuel Controls

THE COMPOUND HELICOPTER
HIGH SPEED CONCEPTS SUBSESSION

By

Andrew Logan
Hughes Helicopters

The advantages and productivity of the conventional helicopter have been widely demonstrated and refined over the last several decades. The excellent hovering capability of the helicopter has made it an indispensable tool for many industries such as off-shore oil drilling, construction, and urban transportation. The helicopter's productivity and applications can be greatly expanded by an improvement in cruise speed which is currently in the 150 knot range. An increase in cruise speed to 250 knots would increase the helicopter's productivity in time sensitive markets such as travel between major metropolitan centers.

The compound helicopter is one excellent method of achieving high speed capability while retaining the hovering advantages of the helicopter. For this discussion, the compound helicopter will be defined as a conventional helicopter with both a wing and auxiliary propulsion. The conventional helicopter rotor is retained. A logical extension of the compound helicopter is the stopping or stowing the main rotor to achieve very high speeds, but this concept is beyond the scope of the present discussion.

The inclusion of wings and auxiliary propulsion circumvents the forward speed limits of the helicopter. In general, the lifting and propulsive force capabilities of the helicopter rotor decrease with forward speed as a result of asymmetric flow conditions encountered by the rotor. On the rotor retreating blade side, the lifting capability drops because the forward speed subtracts from the rotational speed creating a condition of low or negative velocities. On the advancing blade side, the rotational speed is added to the forward speed creating a condition where high Mach number shock waves causes drag and pitching moments. These effects combined with the lateral trim requirement, limit forward speed. The compound helicopter circumvents these limits by lift sharing between the wing and rotor as well as eliminating the need for rotor propulsive force and by slowing rotor (as on XV-1).

Compound Helicopter technology has been demonstrated in flight at speeds up to 300 mph. The early compounds were developed around tip driven rotor systems which autorotated at high forward speeds. Two examples are the McDonnell XV-1 and Fairey Rotodyne. In the sixties, a high level of flight test activity defined compound helicopter technology. This flight testing included the Sikorsky S-61F, Bell Model 533, and the Kaman UH-2, as well as the prototype development of the Lockheed Cheyenne. The Rotor Systems Research Aircraft (RSRA) is currently flying in the compound configuration. This flight experience has demonstrated compound helicopter speed improvements of 60 to 100 knots over conventional helicopters. In support of this flying, extensive wind tunnel testing has also produced a strong baseline of design data.

The status of compound helicopter technology is relatively mature for high speed concepts. The high speed capability of the main rotor has been demonstrated and the major problem areas defined. Rotor capability has been demonstrated to tip Mach numbers to .98 and advanced ratios to 1.0. (It is

interesting to note that 1930 autogyros cruised at tip speed ratios up to 0.6 with conventional cyclic pitch control.) It should be noted that this capability was demonstrated with rotors designed with 1960s technology. Among the problems identified were rotor control sensitivity at high advanced ratios, rotor loads and drag, and high propulsion system weight fractions.

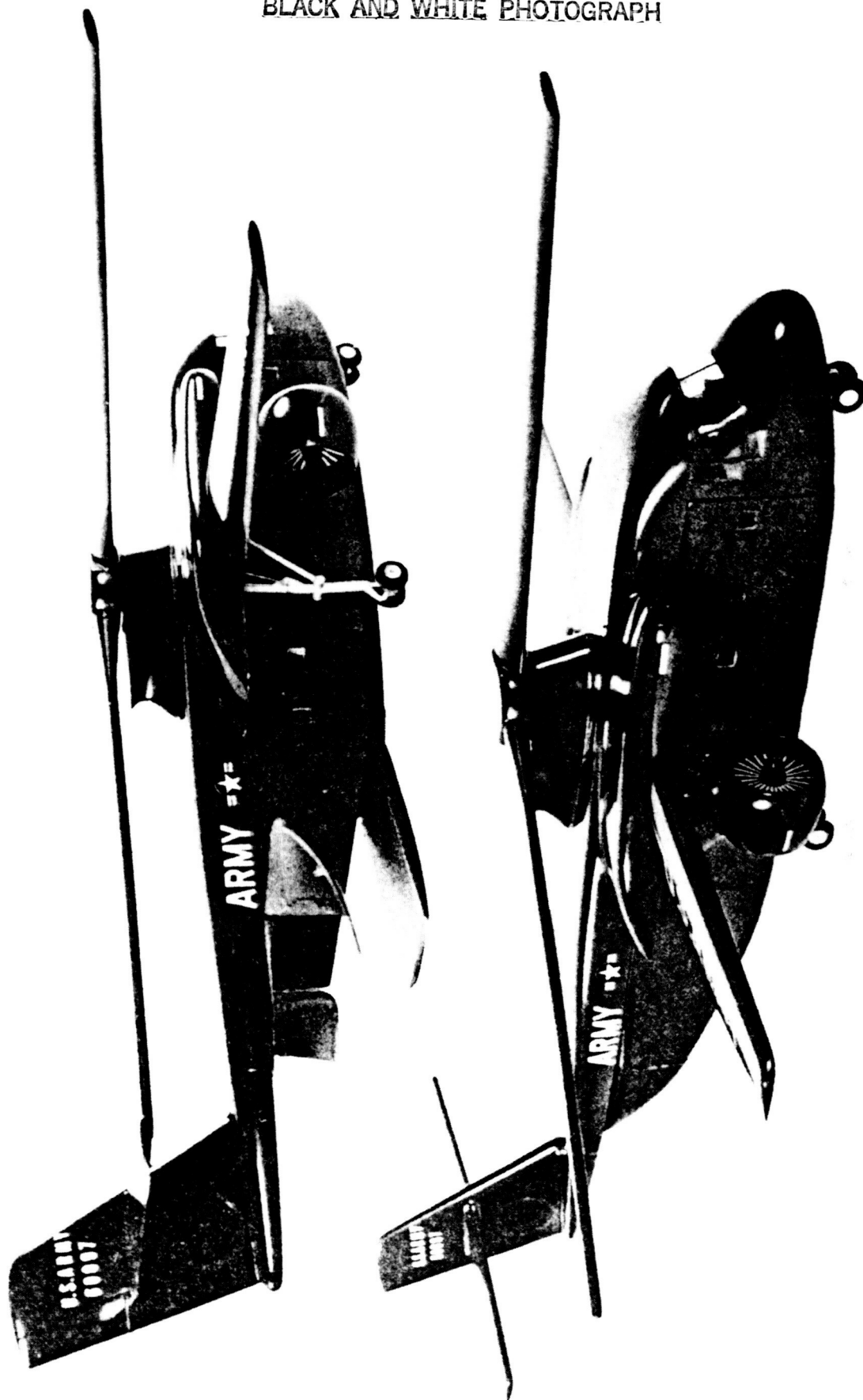
The successful compound helicopters of the 1990s will be designed with improved technology in rotor design, control systems, and propulsion. A rotor specifically designed for 250 knots cruise should be designed and tested utilizing the RSRA. The new compound rotor should incorporate the advances of the 1980s in terms of blade airfoils and planforms as well as the use of composite materials. A reduction in rotor system drag by reducing the size of the hub is a prime objective. An improvement in rotor control systems should be achieved using active controls. The use of Higher Harmonic Control (HHC) on conventional helicopters presently shows the promise of dramatically reducing vibration. The same HHC concepts of sensor, closed-loop feedback, and active blade pitch control should be applied to improve rotor controllability at high advance ratios. Concurrently, directional control systems appropriate to 250 knot cruise should be developed (rudder). A vital part of compound helicopter development is the development of a compound propulsive system. The engines should be capable of providing both drive to the main/tail rotor systems at variable rpm as propulsive force at high speeds. This should be accomplished while maintaining present engine SFC and weight fractions.

The compound helicopter is a promising high speed rotorcraft configuration. This promise can be translated into tomorrow's product by the initiation of a timely development program.

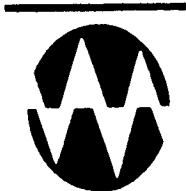


COMPOUND TRANSPORT

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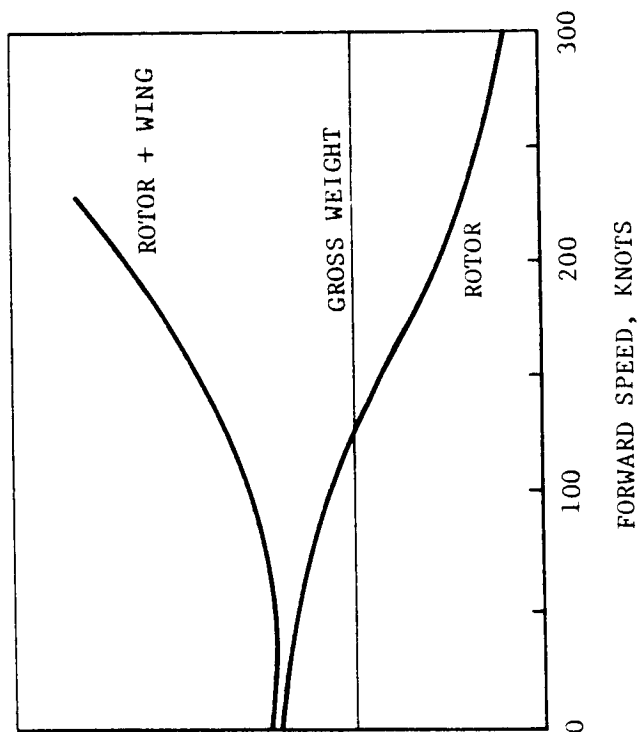


Hughes Helicopters

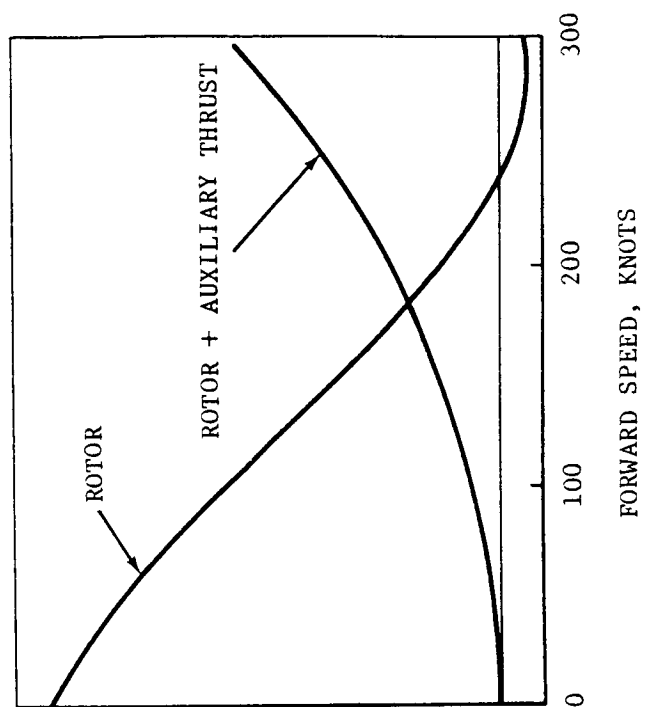


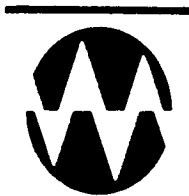
CONVENTIONAL HELICOPTER LIMITS

LIFT

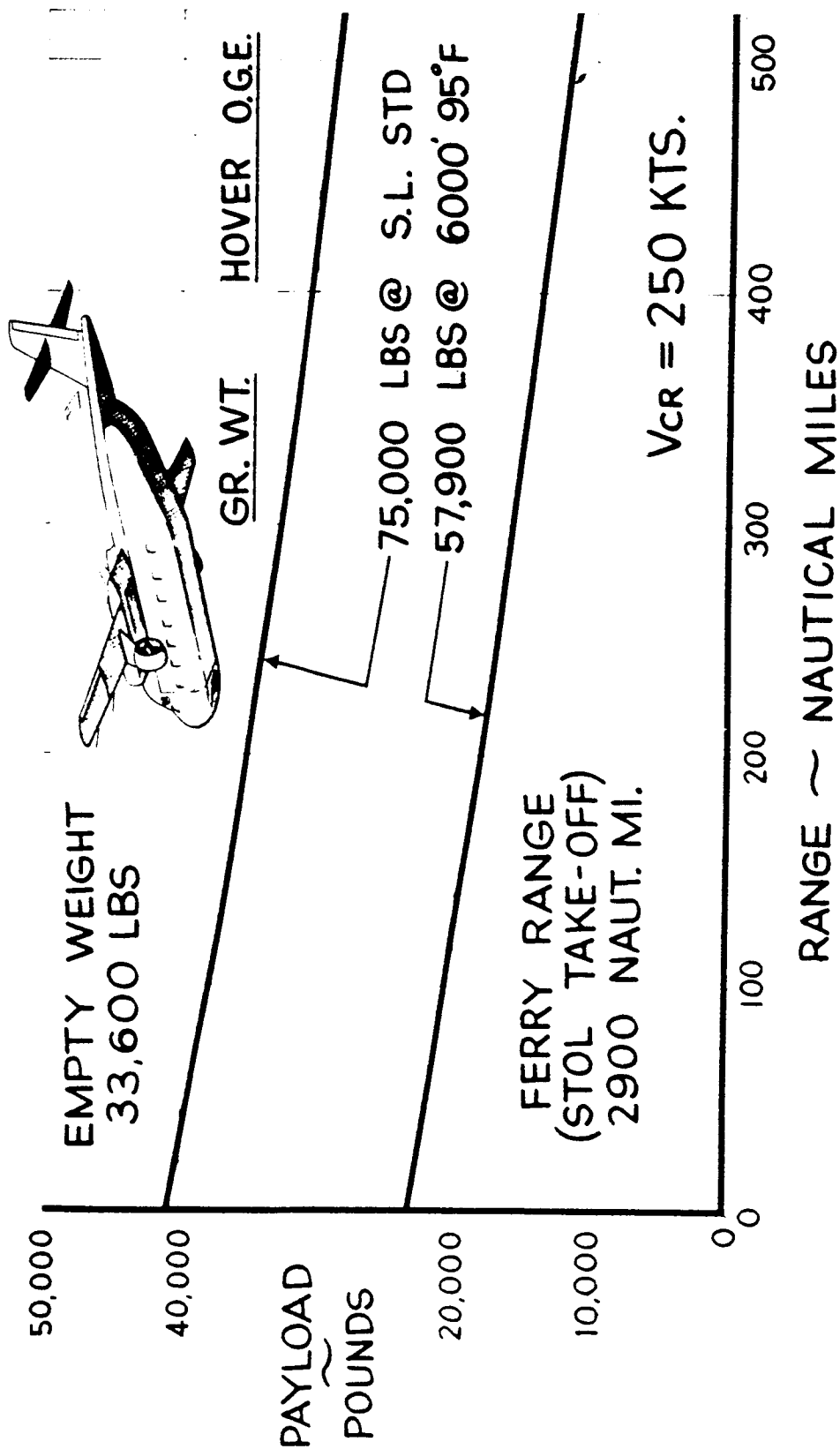


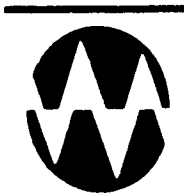
PROPULSIVE FORCE



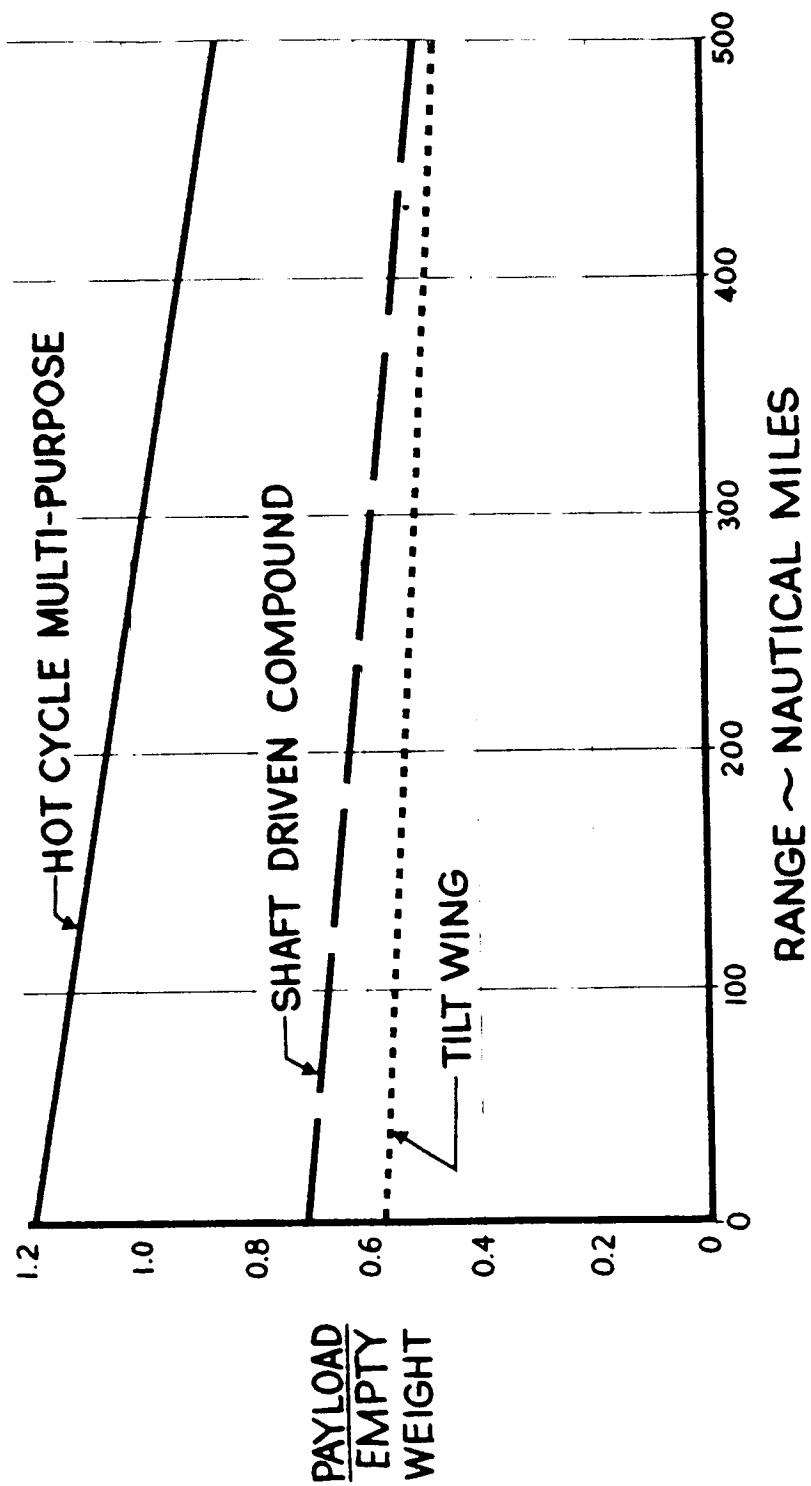


COMPOUND TRANSPORT





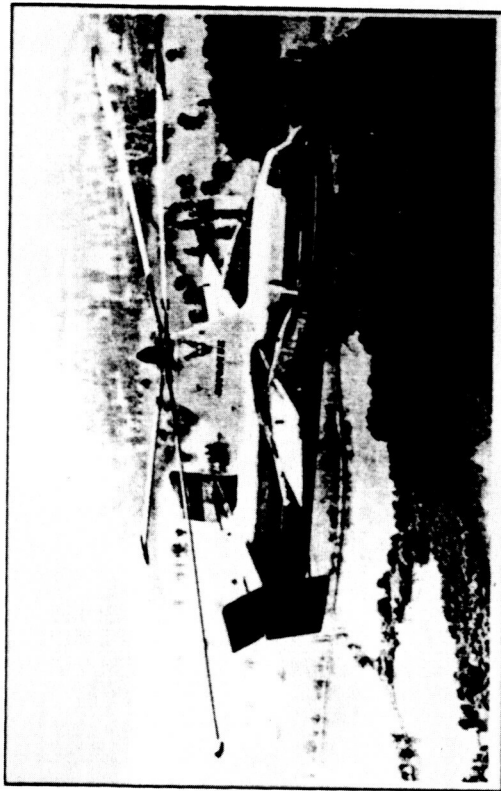
COMPOUND COST EFFECTIVENESS



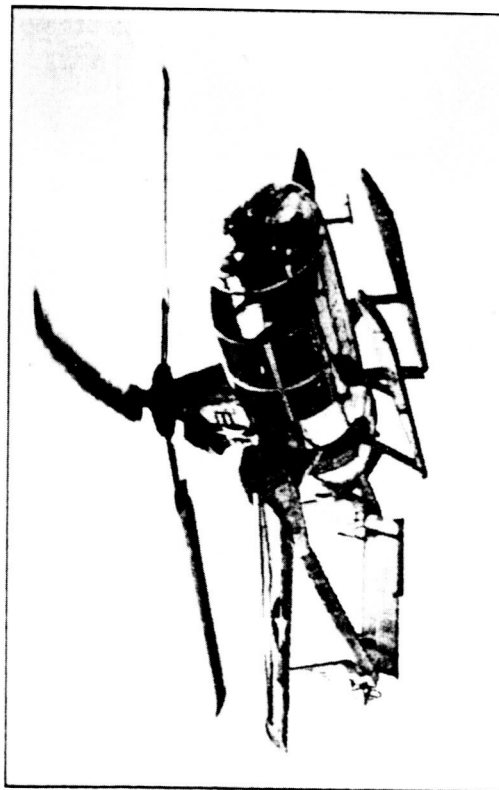


PREVIOUS COMPOUNDS-TIP DRIVEN

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ROTODYNE COMPOUND



XV-1 (McDONNELL)



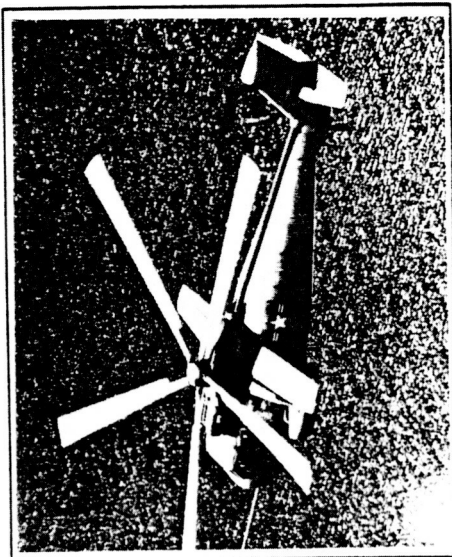
PREVIOUS COMPOUNDS - SHAFT DRIVEN



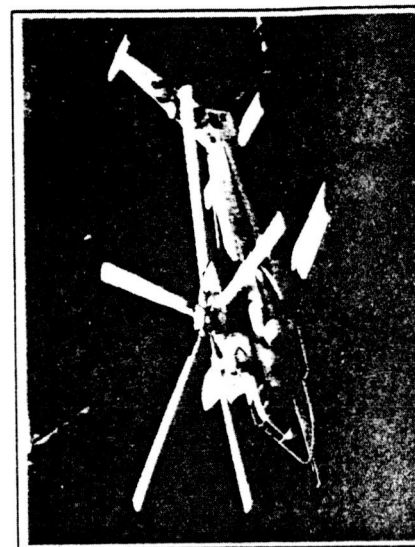
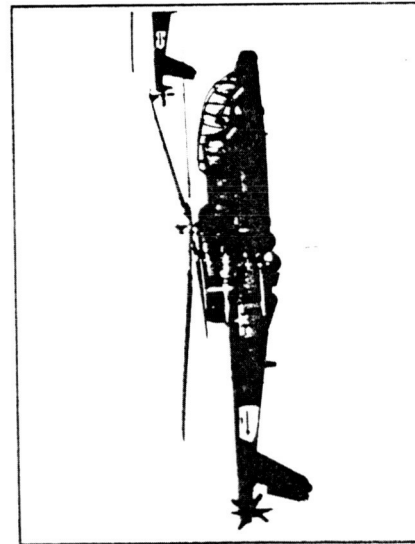
BELL MODEL 533 (YUH-1B)



KAMAN UH-2



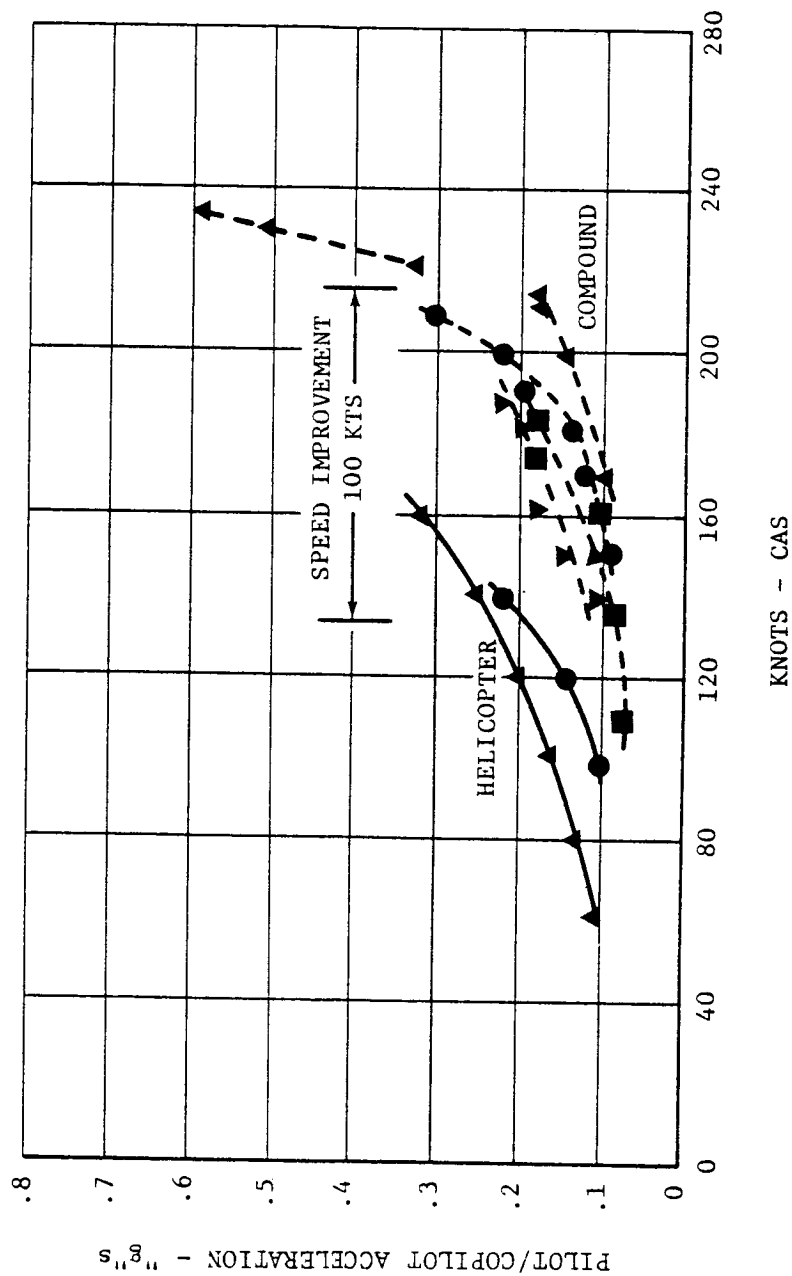
SIKORSKY S-61F



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COMPOUND HELICOPTER SPEED IMPROVEMENT





COMPOUND HELICOPTER TECHNOLOGY STATUS

0 TECHNOLOGY RELATIVELY MATURE

0 ROTOR CAPABILITY DEMONSTRATED

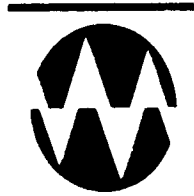
0 PROPULSION NEEDS

0 CONTROLS REQUIREMENTS



ROTOR CAPABILITY

- 0 M_{TIP} TO .98
- 0 ADVANCE RATIO TO 1.0
- 0 1960s TECHNOLOGY



PROPULSION

0 SEPARATE ROTOR POWER & PROPULSIVE FORCE

0 COMPLEX SHAFTING / GEARBOXES



C O N T R O L S

O MAIN ROTOR SENSITIVITY

O HIGH SPEED DIRECTIONAL CONTROL



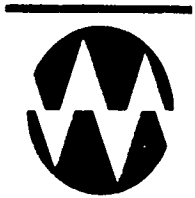
SUGGESTED PROGRAMS

0 DESIGN ROTOR FOR 250 KNOT CRUISE

0 1980s TECHNOLOGY

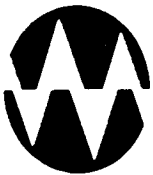
0 TEST ON RSRA

C-2



SUGGESTED PROGRAM

- 0 COMPOUND ENGINE
- ROTOR/PROPULSIVE POWER
- 0 MAINTAIN SFC AND WEIGHT



SUGGESTED PROGRAMS

- 0 ADVANCED CONTROL SYSTEM
- 0 HIGHER HARMONIC CONTROL (HHC)
- 0 ALTERNATE HIGH SPEED DIRECTIONAL CONTROL

ADVANCING BLADE CONCEPT (ABC) TECHNOLOGY NEEDS

By

Ted Carter
Sikorsky Aircraft

Helicopters have developed indispensable roles in both military and civilian missions, but in virtually every situation the missions that are unique to helicopters demand confined area landing, precision hover, or nap of the earth capabilities. There has always been a desire for higher speeds to improve productivity and military superiority, but when alternatives to helicopters have been developed they have almost always failed because of limited low speed safety margins or control precision. And as civil helicopters expand into a larger passenger carrying role, we must anticipate tighter and tighter standards for Cat A confined area operations. The ABC offers the opportunity for higher speeds (and higher altitudes) while enhancing low speed safety with power margins and performance significantly better than even the most modern of today's helicopters.

The ABCTM helicopter with its 250 knot speed and 25,000 ft. altitude capability nearly doubles the speed-altitude envelope of the helicopter but still operates at low disc loading, and with its high hover efficiency and the power installed for high speed, will hover with one engine inoperative, thus effectively eliminating the field length requirement generally needed to provide a safe landback capability in case of engine failure.

Because the risks and non-recurring cost of any new configuration are higher than a helicopter manufacturer could be expected to assume alone, military co-support is highly desirable. In addition to high speed, the ABC concept offers the military compactness, simplicity, low down wash, and agility throughout its speed range, making it ideal for missions where high speed combined with forward basing, shipboard compatibility, or nap-of-the-earth survivability is required. Therefore, the ABC satisfies an urgent need in both the civil and military spheres.

ABC Concept Current Status

The XH-59A ABC concept demonstrator has nearly completed its flight envelope expansion, and has achieved a speed of over 250 knots and an altitude of nearly 24,000 feet. The testbed vehicle flight test program and accompanying analysis has proven the concept. However, because it was conceived purely as a concept demonstrator for both pure helicopter and auxiliary propulsion versions the XH-59A comprised a series of compromises in blade shape, twist, rotor materials, shaft tilt, auxiliary propulsion, empennage and flight controls. The next step is to implement a program to demonstrate significant improvements in weight fraction, cruise efficiency, hover power margin, agility, and vibration.

Proposed Technology Program

Using the results of the flight test program conducted to date, we recommend a series of subsystem technology development programs consisting of component definition, design, fabrication and test.

An integrated propulsion system is needed that permits the same gas generator to drive both the rotor and a propulsor so that all the installed power is available in both cruise and hover. Advanced propulsors are needed that deliver peak efficiency at Mach 0.4 and at power loadings high enough to permit compact packaging. Advanced airfoils and hub fairings are needed to maximize aerodynamic efficiency. Composite blades and hubs with bearingless blade retention will reduce weight and complexity. Higher harmonic control will reduce vibration to levels where heavy absorbers will no longer be required. And pilot workload and ride quality will improve with incorporation of active controls and reduced empennage.

The potential of these advances should be confirmed in full scale tests in the 40 x 80 and on ground simulators. The results of the subsystems technology development programs would then be incorporated and tested in a second generation flight vehicle, with integrated propulsion system, composite rotors with optimized geometry, and higher harmonic control combined with fly-by-wire and active flight control. An ABC technology development program incorporating these improvements could be completed by 1985, to be available for full scale development for military or civil programs.

The development of low disk loading VTOL has reached a critical decision point. The ABC and tilt rotor flight programs are about done and the technology base is firming up. But Navy interest is evaporating because they are faced with a short term assets problem that will require a significant investment in current technology. Army interest is increasing but no funds are yet available. Current NASA funding is insufficient to continue constructive flying.

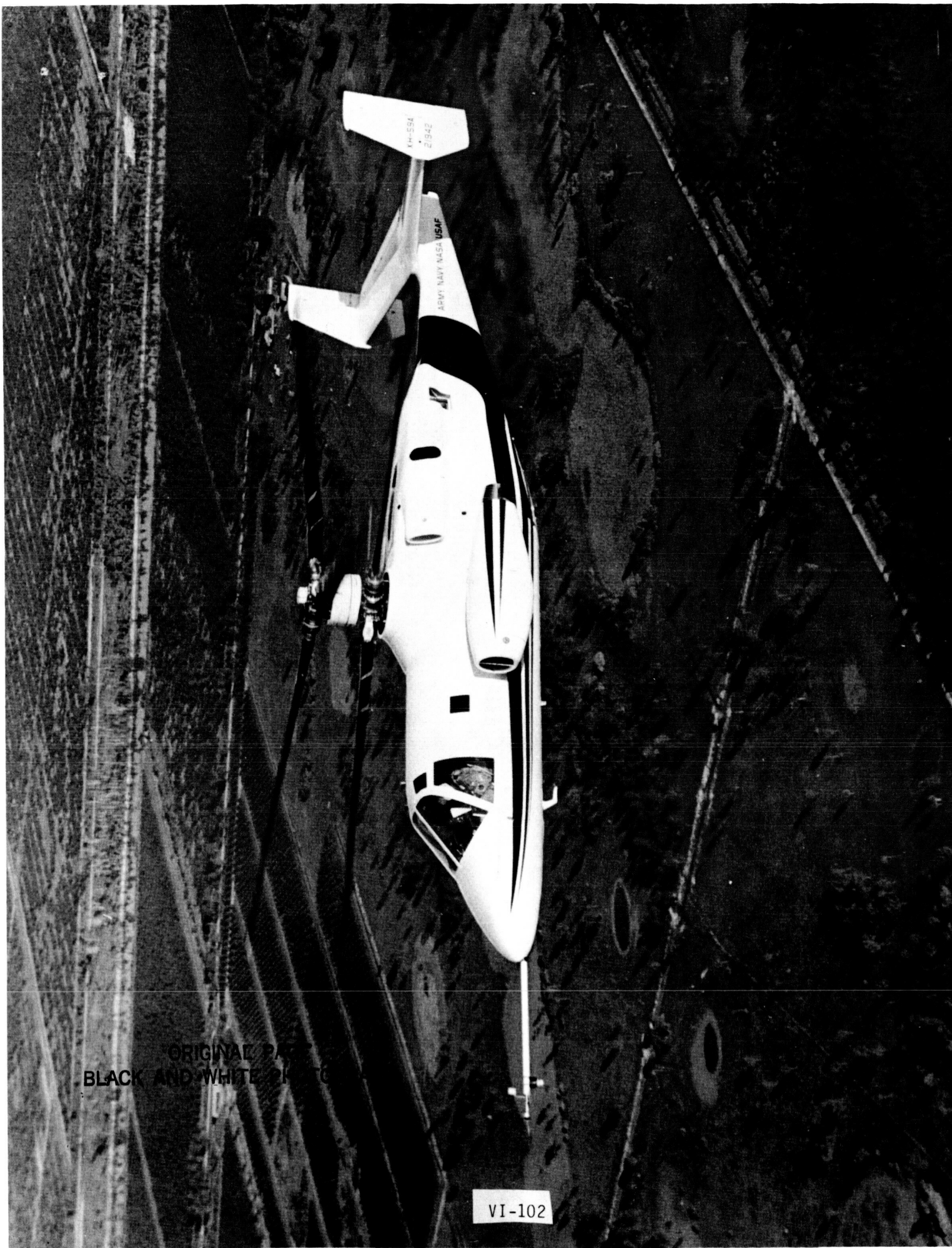
Now is the time for NASA to take the lead in the activity necessary to translate demonstrated high speed, low disc loading technology into matured technology for cost-effective mission hardware.

A B C T E C H N O L O G Y N E E D S

T E D C A R T E R

S I K O R S K Y A I R C R A F T

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VI-102

ADVANCING BLADE CONCEPT (ABC™) DEMONSTRATOR

This Advancing Blade Concept technology demonstrator aircraft was designed and built by Sikorsky Aircraft Division of United Technologies Corporation to evaluate the feasibility of the ABC rotor system through flight testing as a pure helicopter, and at high speed in the auxiliary propulsion mode, using side-mounted jet engines.

The aircraft, designated the XH-59A, is under Army/Navy/NASA contract and is now being flight tested at Sikorsky Aircraft's West Palm Beach, Florida facility. The auxiliary engines were provided by the U.S. Air Force.

PURE HELICOPTER

Aircraft flew from 1975-1977 at Sikorsky Aircraft's Stratford, CT plant. At that time it demonstrated:

PERFORMANCE

- Retreating blade stall prevented by Advancing Blade Concept
- 160 knots level flight speed
- 192 knots in a dive
- 156 knots level flight at 10,000 ft
- Excellent hover performance

HANDLING QUALITIES

- High control power
- SAS-off through entire flight envelope

Low Noise

Low Stress and Loads at All Flight Conditions

AUXILIARY PROPULSION

Two J-60 jets added in 1977 to provide auxiliary propulsion for flights up to 300 knots. In 1980 the rotors were re-indexed to 0° phasing. Tests to date at West Palm Beach facilities demonstrated:

PERFORMANCE

- Proper power sharing between rotor and jets
- Level flight to 238 knots
- 5,000 ft/min vertical rate of climb at 150 knots
- 5,000 ft/min vertical rate of descent at 160 knots
- .3 to 1.78g's at 210 knots TAS

HANDLING QUALITIES

- Throttle chops to rotor or jets easily handled
- 360° hovering turns in 7 seconds
- 82°/sec peak turning rate
- Tested at 0° and 60° rotor phasing

Further objectives are:

- Level flight to over 250 knots
- Reduce rotor RPM at high forward speed
- Load factor from 0 to 2.0g's to V_{max}

OPPORTUNITIES FOR HIGH SPEED ROTORCRAFT

- . HELICOPTERS INDISPENSABLE TO BOTH CIVIL & MILITARY OPERATIONS
- . NOE & CONFINED HELIPORTS DICTATE HOVER AND LOW SPEED POWER MARGINS & AGILITY
- . HIGH SPEED CAN SIGNIFICANTLY IMPROVE CIVIL PRODUCTIVITY & MILITARY SUPERIORITY
- . MANY VTOL APPROACHES ARE POSSIBLE CONTENDERS BUT ABC PROVIDES SOLUTION TO BOTH REQUIREMENTS
- . COSTS TO DEVELOP & QUALIFY COST EFFECTIVE ABC OR OTHER HIGH SPEED APPROACHES MAY REQUIRE JOINT CIVIL/MILITARY APPLICATION
- . THEREFORE TECHNOLOGY DEVELOPMENT PLANS MUST CONSIDER BOTH

DESIGN REQUIREMENTS

COMMUTER

- CATEGORY A TAKE-OFF AND LANDING FROM CONFINED AREAS (HELIPORTS)
- HELICOPTER AIRWAYS
- LANDING AND NAVIGATION AIDES
- 200-300 NAUTICAL MILES
- 20 TO 30 PASSENGERS

EXECUTIVE

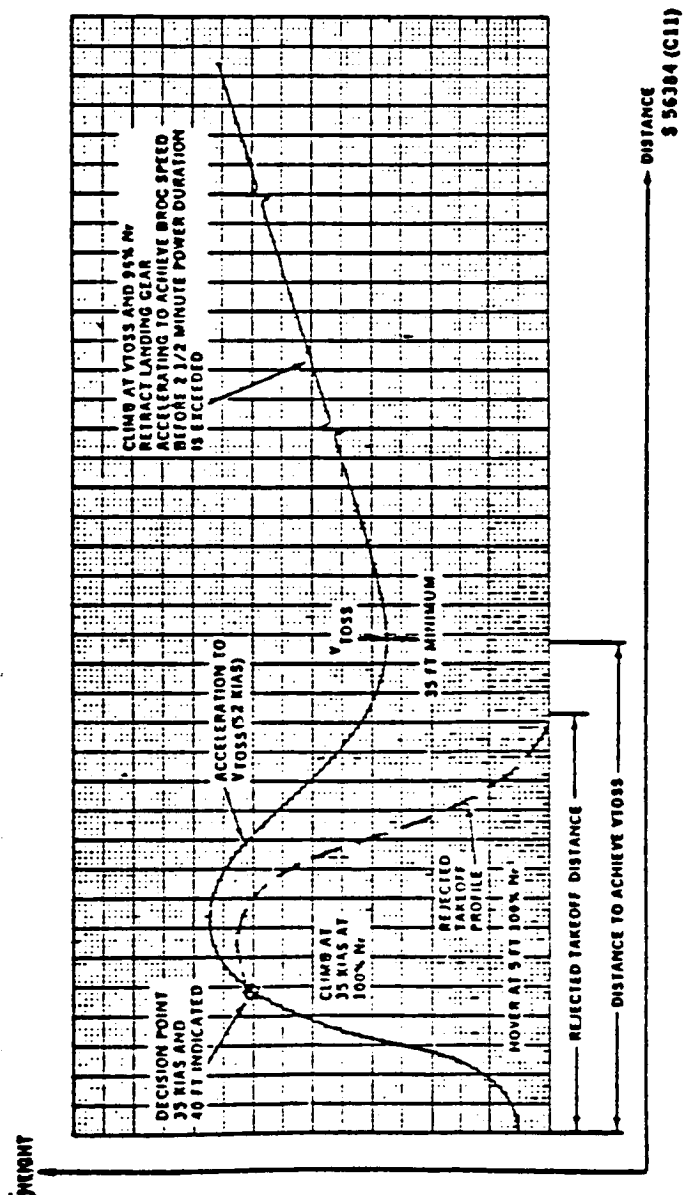
- CATEGORY A TAKE-OFF AND LANDING FROM CONFINED AREAS
(HELIPORTS AND ROOF TOPS)
- 200 NAUTICAL MILE RANGE

OFF-SHORE OIL

- TAKE-OFF AND LANDING FROM SMALL PLATFORMS
- LIMITED OR NO EXPOSURE TO SINGLE ENGINE FAILURE
- 500-600 MILE RANGE MAX
- 20 TO 40 PASSENGERS

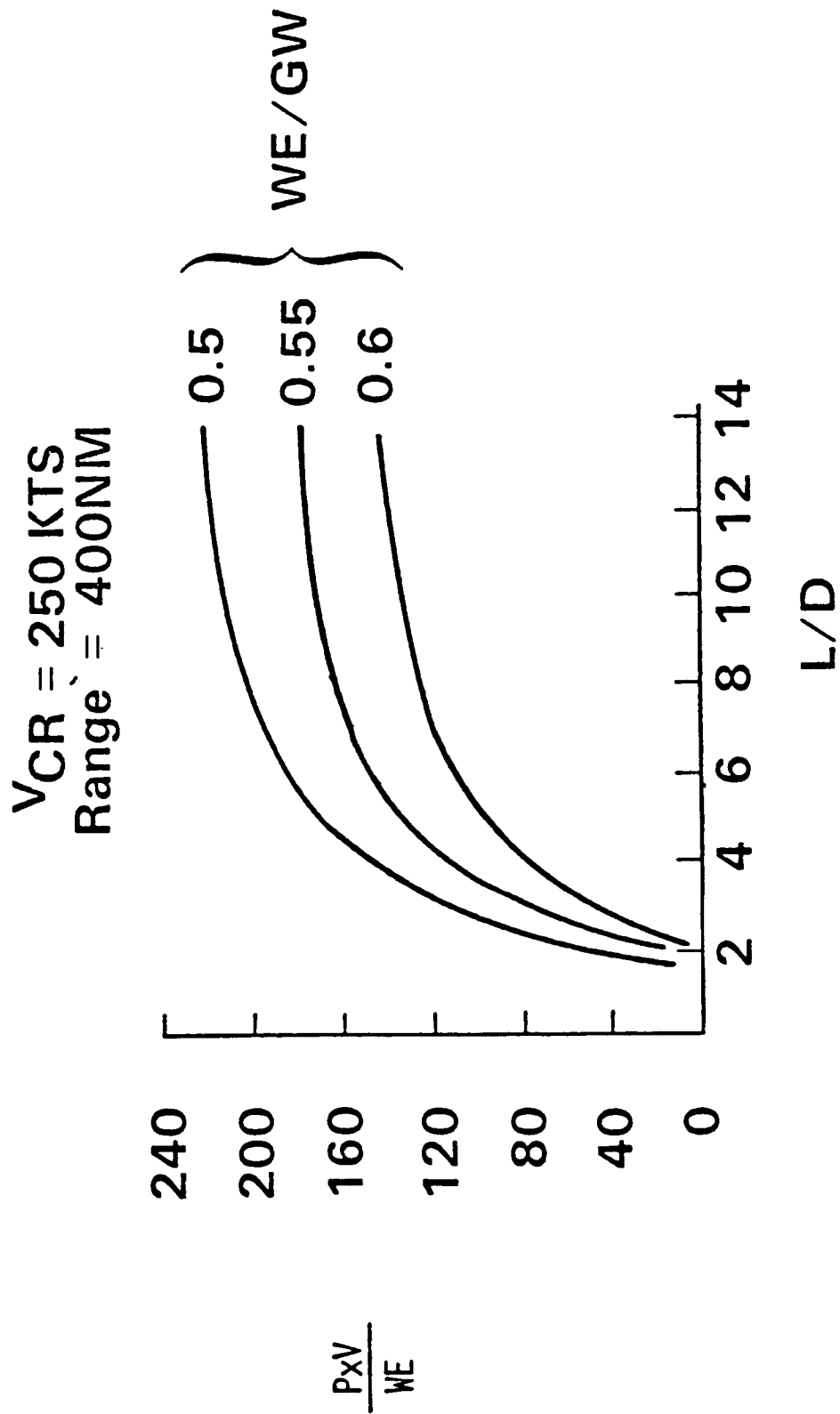
HOW DOES THIS PRIORITIZE TECHNOLOGY REQUIREMENTS?

CATEGORY "A" TAKEOFF PROFILE



ORIGINAL PAGE 13
OF POOR QUALITY

PRODUCTIVITY DEPENDS MORE ON STRUCTURAL
 THAN AERODYNAMIC EFFICIENCY

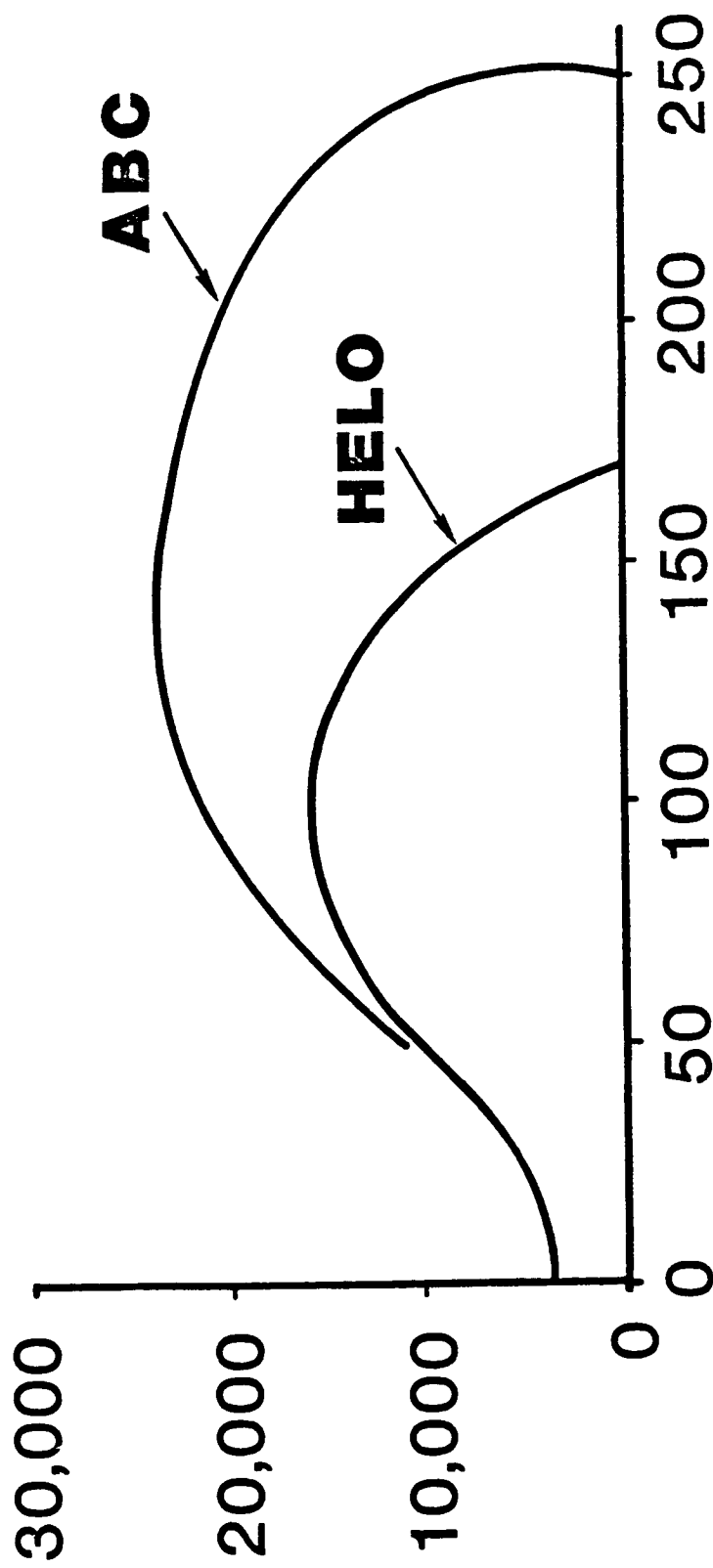


ABC GOALS

- . EXTEND SPEED/ALTITUDE ENVELOPE OF ROTORCRAFT
 - . > 200 KNOTS
 - . > 20,000 FT.
- . INCREASE PRODUCTIVITY
- . MEET CONFINED HELIPORT & OIL RIG CATEGORY A REQUIREMENTS OF THE 1990's
- . MEET NOE, AGILITY & DECK SAFETY REQUIREMENTS OF ADVANCED MILITARY HELICOPTERS

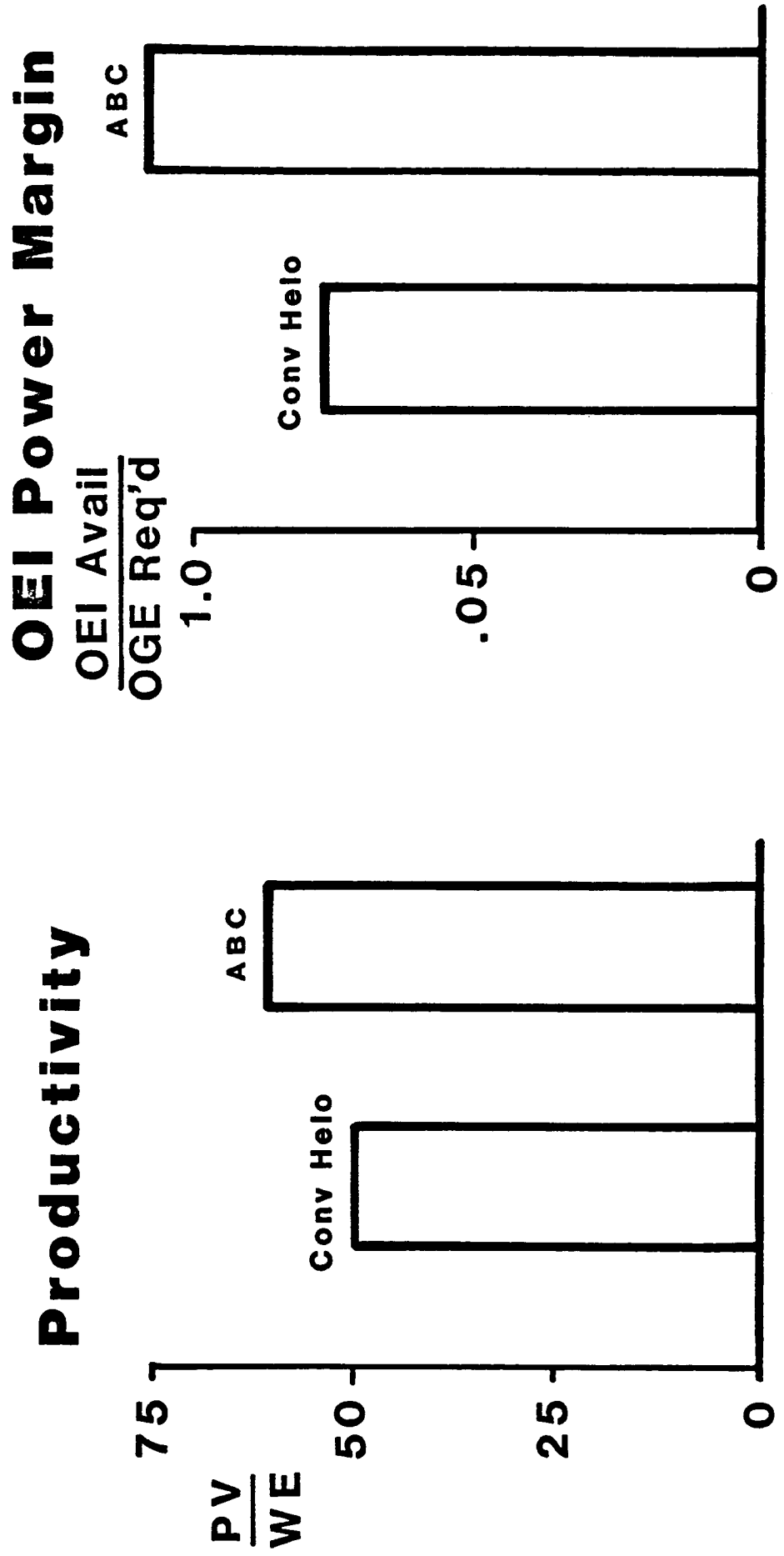
ABC OFFERS SIGNIFICANTLY MORE SPEED AND ALTITUDE THAN CONVENTIONAL HELICOPTERS

Altitude - Ft



TAS - Kn

CIVIL ABC OFFER HIGH SPEED PRODUCTIVITY WITH SUPERIOR LOW SPEED SAFETY



ATTRIBUTES OF ABC FOR MILITARY MISSIONS

FOR

.	HIGH DASH SPEED	TIME LATE, QUICK REDEPLOYMENT, AIR TO AIR
.	COMPACT	SMALL SHIP, HELIPORT, PLATFORM NOE
.	LOW DOWNWASH	UNPREPARED AREAS & PERSONNEL PROXIMITY
.	SIMPLE TRANSITION	LOITER \longleftrightarrow DASH MISSIONS (AIR TO AIR) IFR APPROACH FOR CIVIL MISSIONS
.	EFFICIENT HOVER/LOITER	ASW, AEW & SEMA MISSIONS
.	VERY STIFF ROTOR SYSTEM	HIGH WIND START/STOP (SHIPS/PLATFORM)
.	SIMPLICITY	RELIABILITY/MAINTAINABILITY
.	LOW RADAR CROSS SECTION	SURVIVABILITY
.	LOW SPEED AGILITY	NOE

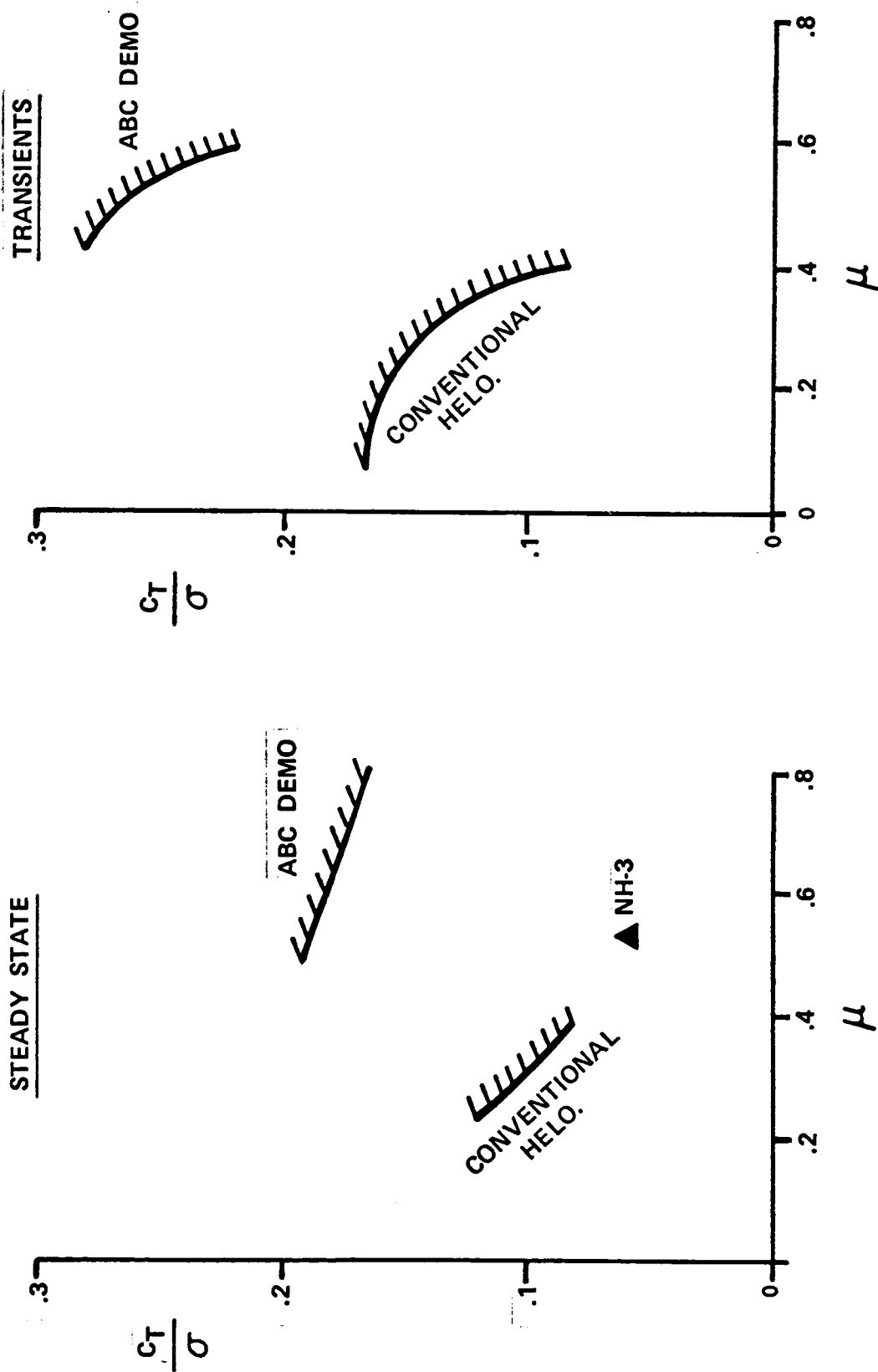
WHERE DO WE STAND?

WHAT DO WE NEED TO DO?

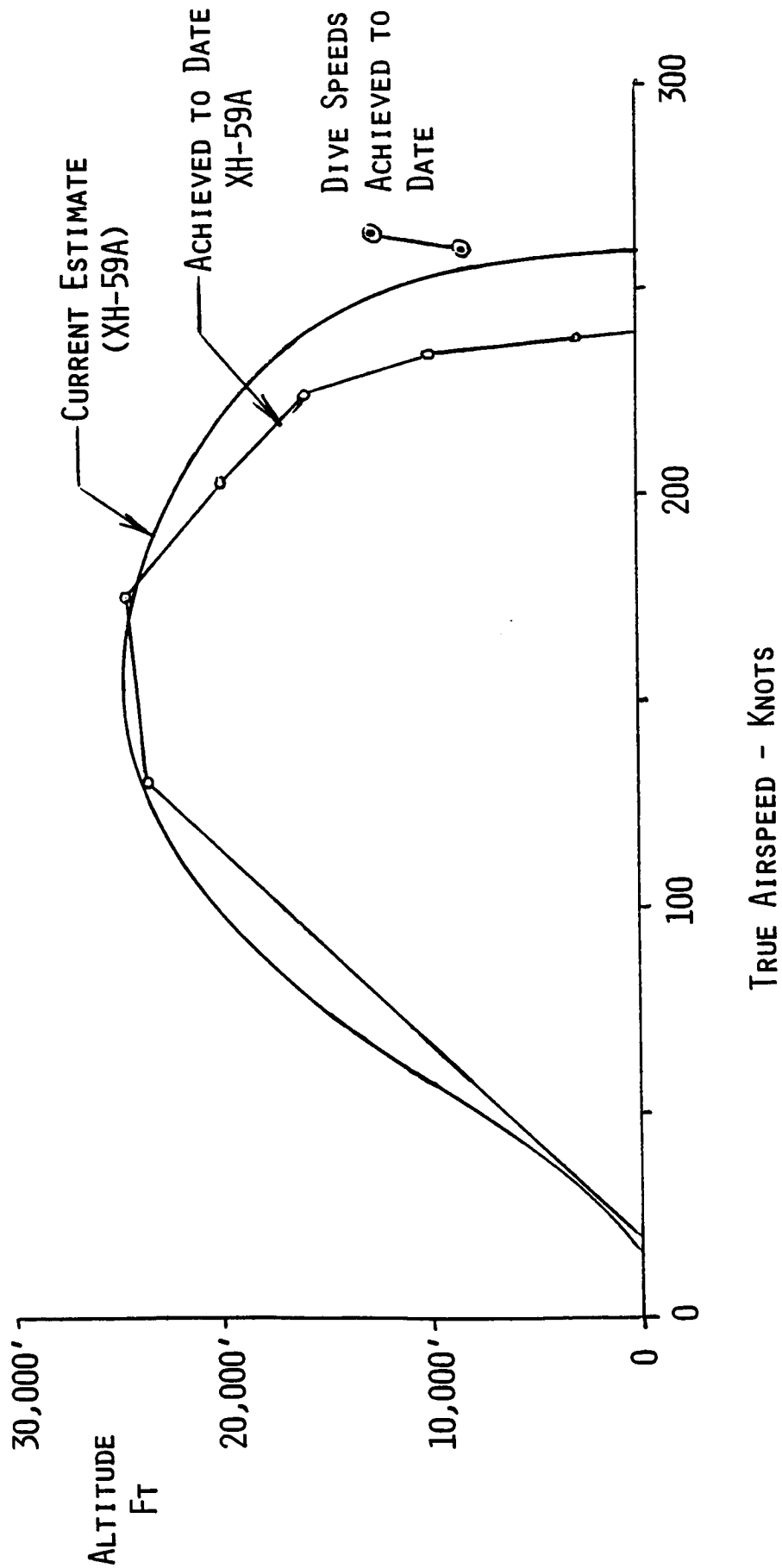
FLIGHT ENVELOPE EXPANSION

IS ABOUT COMPLETE

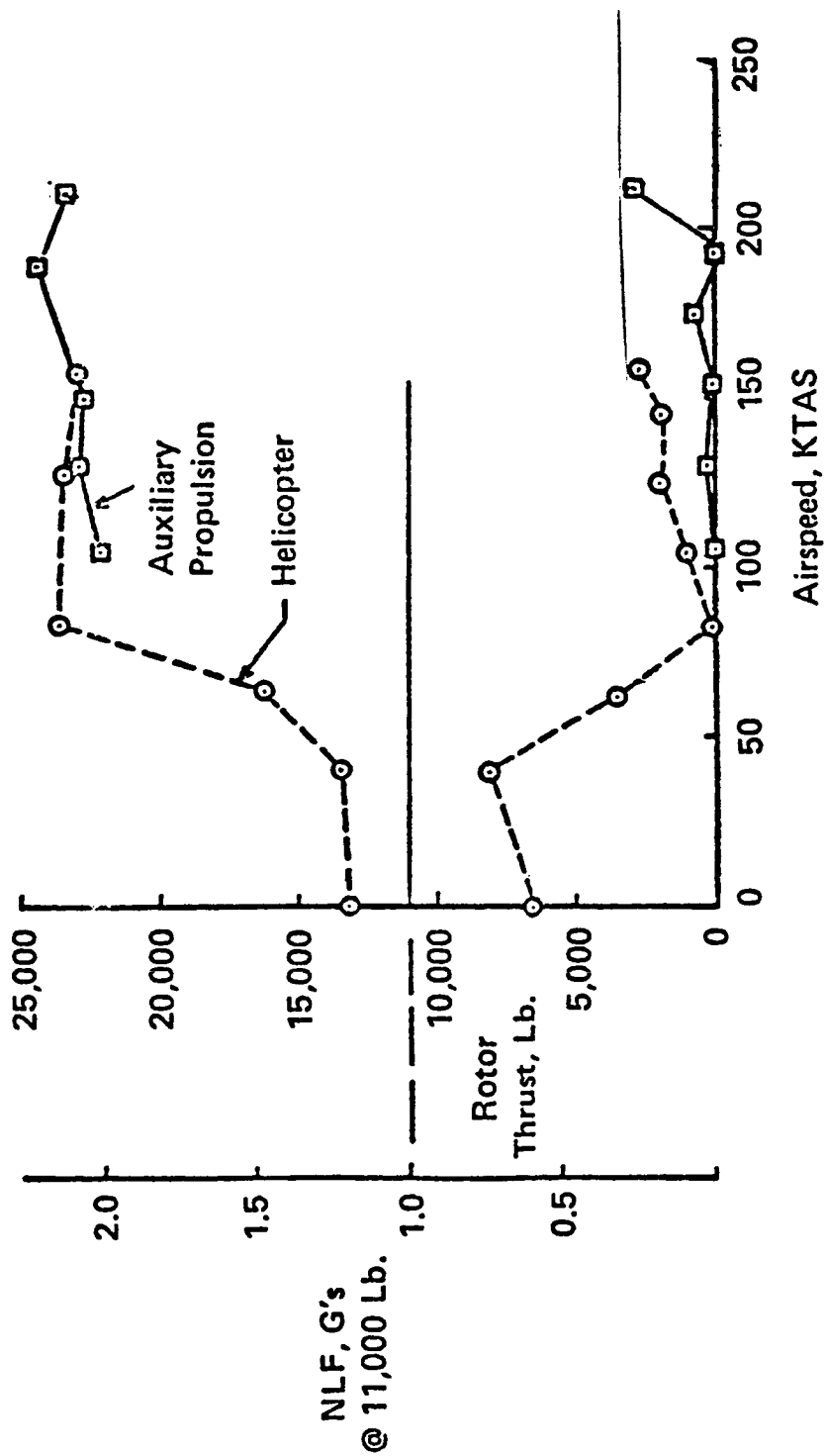
ABC ABILITY TO CARRY LIFT AT HIGH SPEEDS CONFIRMED



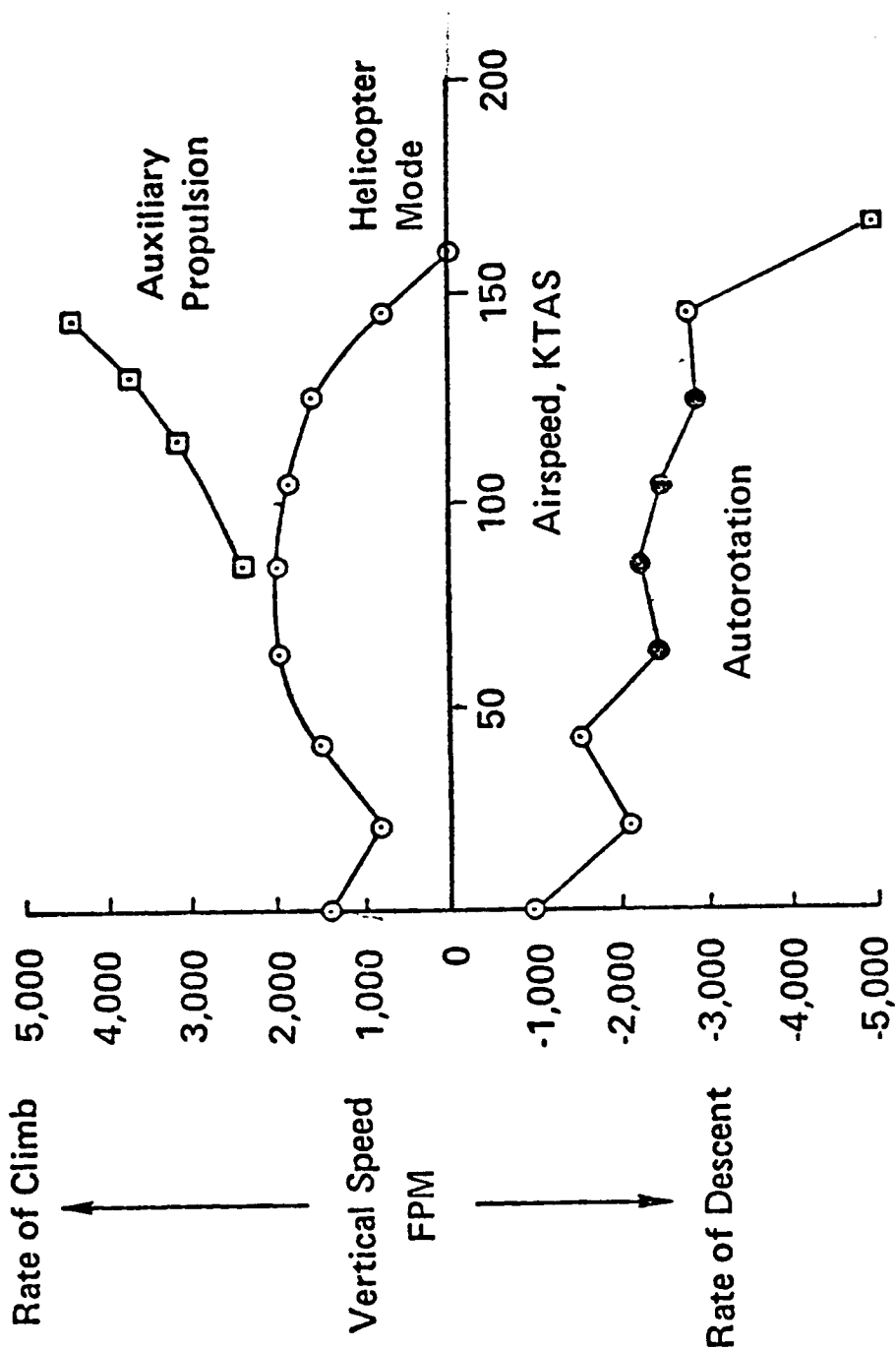
ABC ALTITUDE/SPEED ENVELOPES



DEMONSTRATED LOAD FACTOR ENVELOPE



DEMONSTRATED CLIMB/DESCENT ENVELOPE



ABC PROGRAM DEVELOPMENT – OPPORTUNITIES

- I Exploratory Flight Test**
- II Component Technology Development**
 - Rotor Development
 - Aerodynamic Development
 - Control Development
 - Integrated Propulsion
- III Operational Assessment**
 - Economic Studies
 - Ground Based Simulation
 - Flight Evaluation
- IV Component Size Assurance Demonstration**

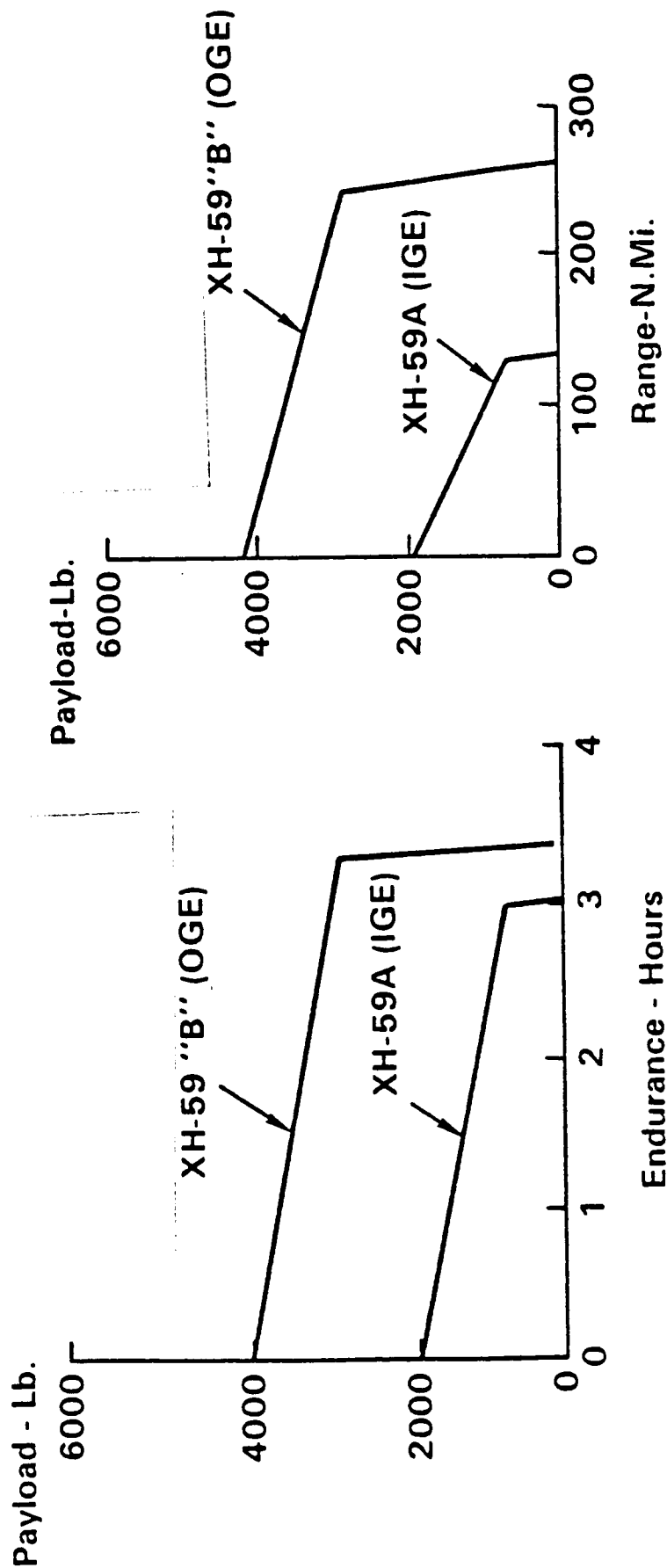
POSSIBILITIES FOR FURTHER USE OF XH-59A

- . OPERATIONAL DEMONSTRATION
- . VIBRATION ISOLATION
- . PERFORMANCE IMPROVEMENT WITH
 - . RPM REDUCTION
 - . ROTOR HEAD DRAG REDUCTION
 - . EMPENNAGE REDUCTION
- . DOWNSTREAM TEST BED FOR:
 - . ADVANCED ROTOR
 - . INTEGRATED PROPULSION
 - . HHC

SECOND GENERATION ABC

	XH-59A	2nd Generation, XH-59 "B"	Method for Improvement
Performance			
Hover Power Margin S.L.-Std.	IGE on 2 Engines	OGE OEI	Integrated Propulsion System
Specific Range, NM/LB.	.10	.18	
Empty Weight Fraction	.77	.60	Composite Rotor Integrated Propulsion SYSTEM
			REDUCED EMPENNAGE
Vibration, 200 Knots			
Cockpit Vertical	0.50g	0.15g	HHC and/or
Cockpit Inplane	0.65g	10g	Isolators

SECOND GENERATION ABC



AN INTEGRATED PROPULSION SYSTEM HEADS THE DEMONSTRATOR IMPROVEMENT LIST
BUT AN ADVANCED ROTOR IS THE KEY NEW TECHNOLOGY

	ADVANCED ROTOR					ADV. CONTROL	
	INTEGRATED PROPULSION SOLUTION	ADVANCED ROTOR GEOMETRY	COMPOSITE BLADES	LESS HUB BEARING-ROTOR HEAD FAIRING	REDUCED EMPENNAGE THRU ACT	FBW & PARAMETER SCHEDULE	HIGHER HARMONIC CONTROL
OPTIMUM CAT A CAPABILITY	X						
REDUCED WEIGHT EMPTY	X	X		X	X		
IMPROVED FUEL EFFICIENCY	X		X	X	X	X	
IMPROVED R/M	X	X	X			X	
REDUCED VIBRATION		X					X

PROPULSION DEVELOPMENT

**How Can Advanced Engine Technology
Improve on Existing Option?**

**ABC Needs A Broadband Multispeed Engine Designed
for Efficient Operation from 70% to 100% RPM**

OPTIONS FOR PROPULSION SYSTEM

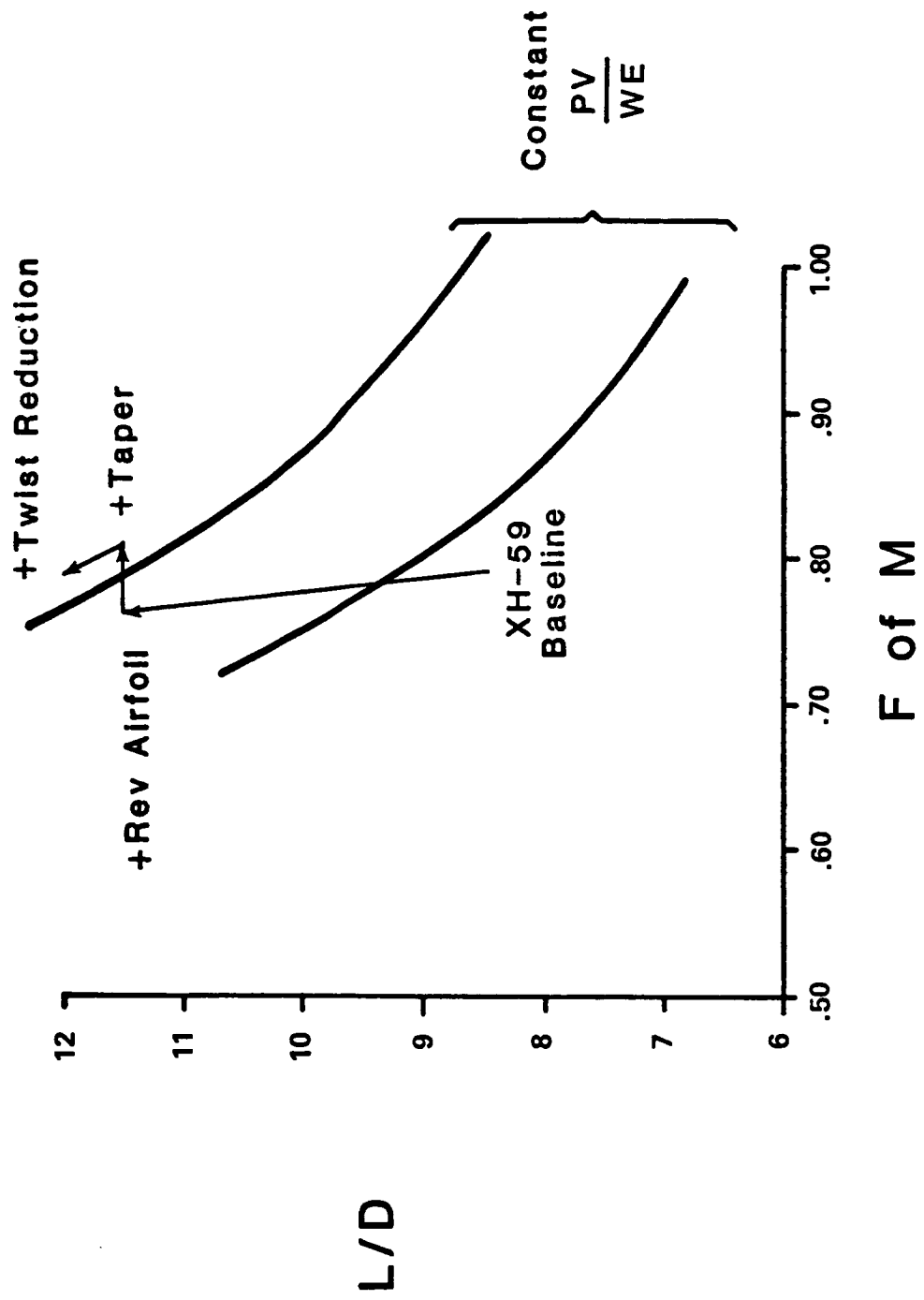
Solution	Technology Requirement
1. Autorotate Rotor at High Speed	Freewheel/Clutch Plus Collective Control of RPM
2. Two Speed Transmission	Propulsor Clutch Plus Two Speed Transmission
3. Convertible Engine	Two Independent Engine Power Inputs with Appropriate Control
4. Broad Band Multispeed Engine	Engine and Propulsor Designed for Efficient Operation at 70% Normal RPM

OBJECTIVES OF 2ND GENERATION ROTOR PROGRAM

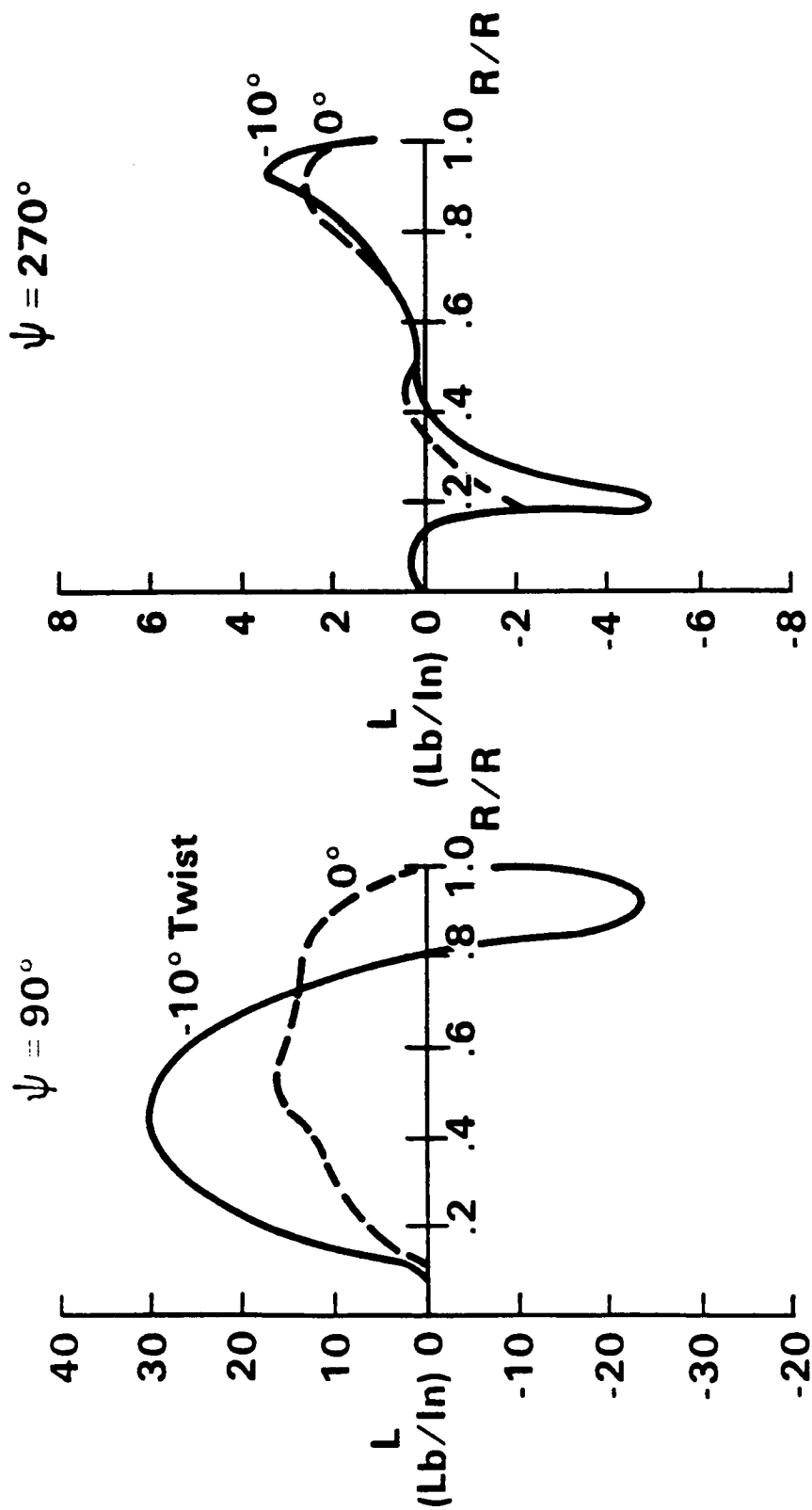
Demonstrate:

- Improved Performance with Optimized Twist, Airfoil PLATFORM AND TIP
- Weight Reduction Potential of 28% with Composites
- Improved Reliability with Blade Retention Improvement
- Reduced Vibration with HHC,

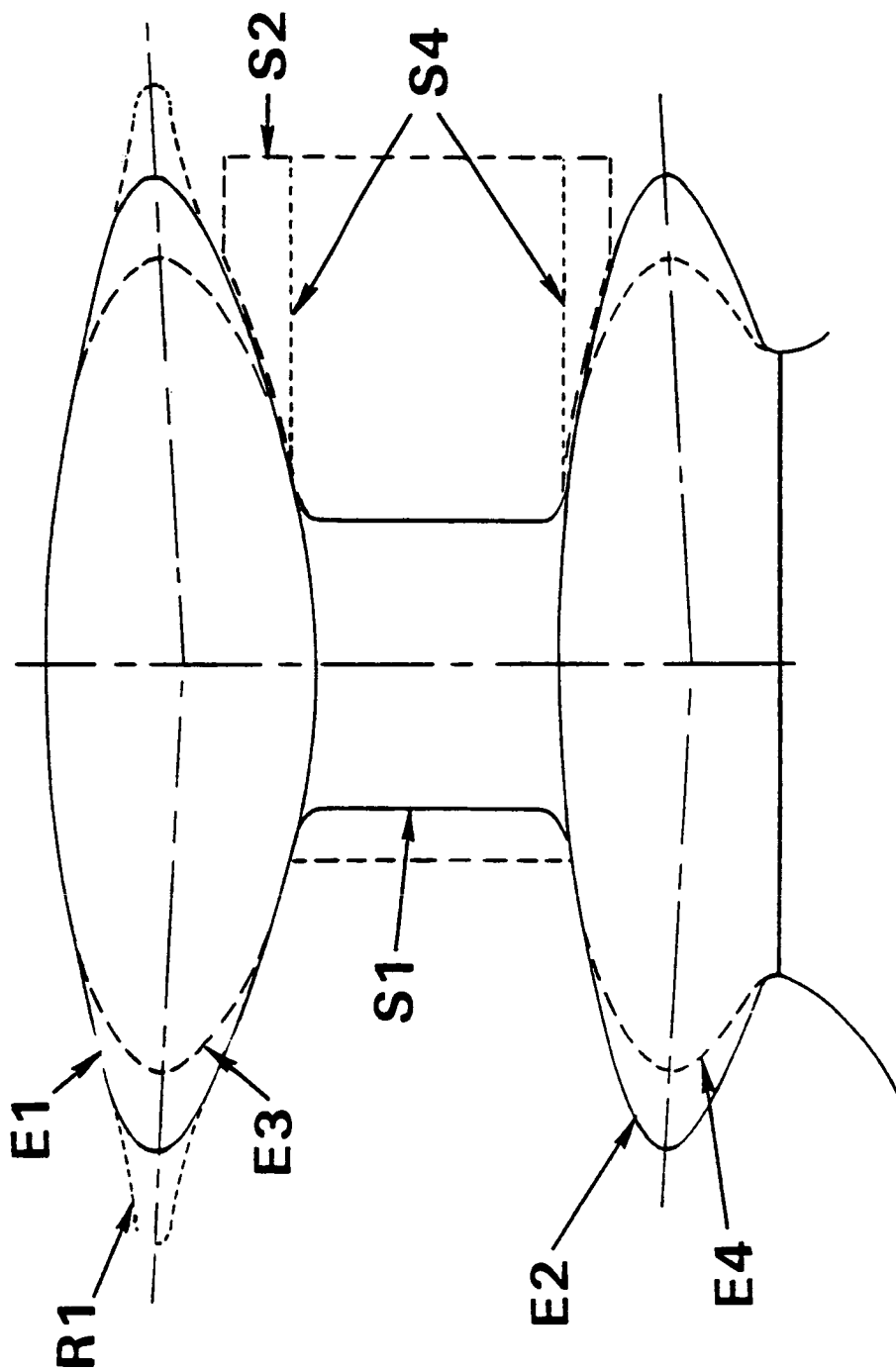
ADVANCED ROTOR CAN IMPROVE L/D AND RETAIN HIGH FIGURE OF MERIT



BLADE TWIST OPTIMIZED FOR HIGH SPEED WILL IMPROVE LOADING AND PERFORMANCE

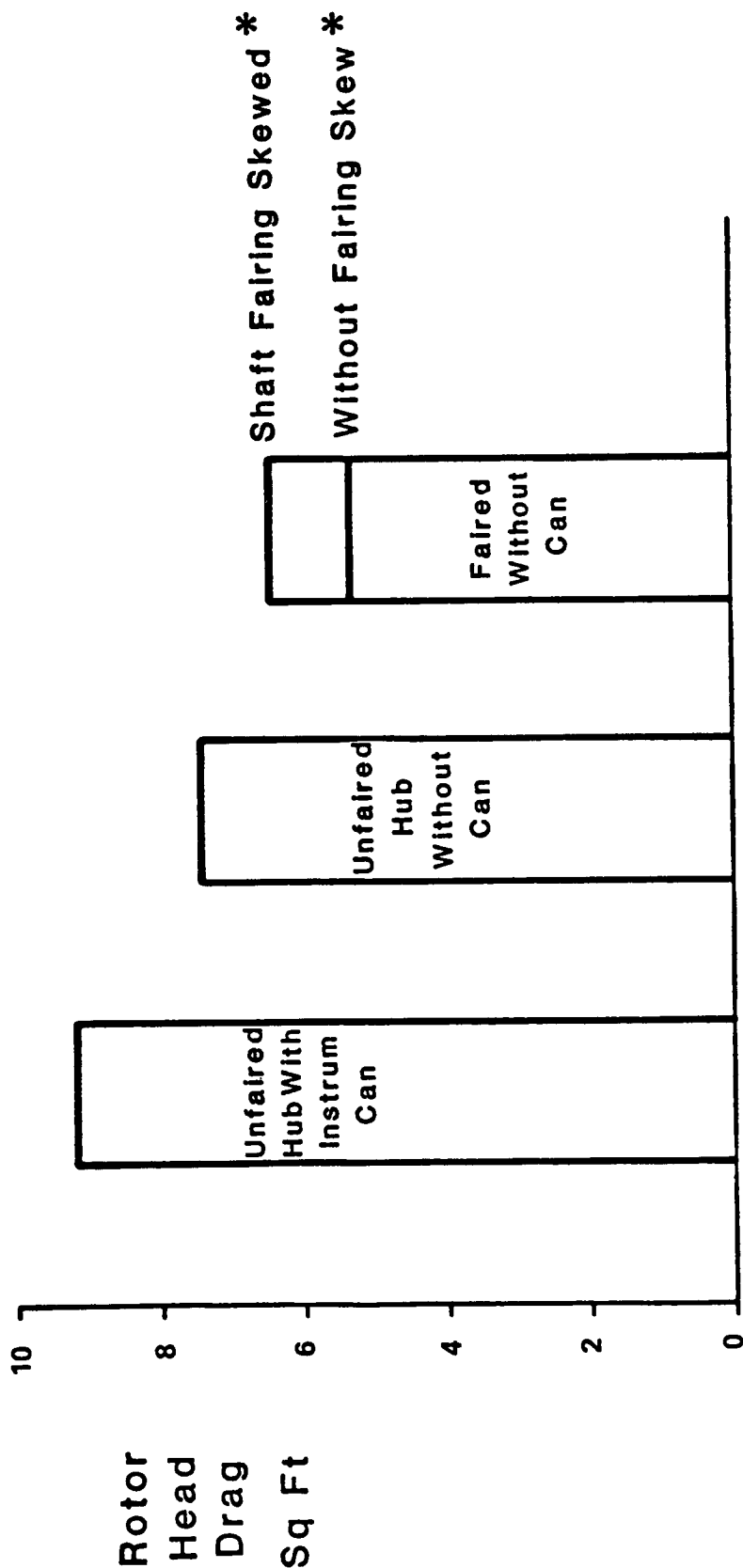


1/5 ABC HUB FAIRINGS TESTED



XH-59A HUB DRAG REDUCTION

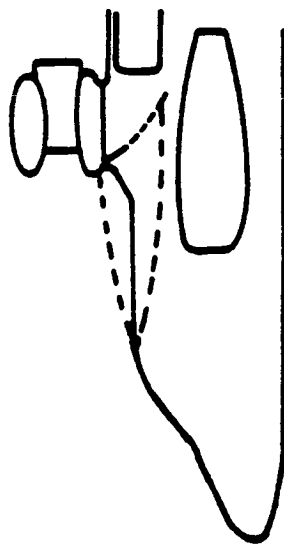
M=0.263 With Rotation And Blades



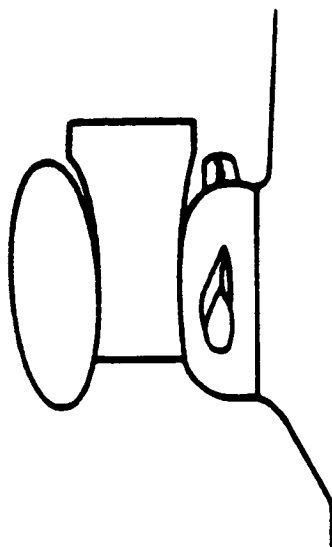
* Based on interpretation of incomplete full scale results and 1/5 scale testing

CANDIDATES FOR ANALYSIS AND FOLLOW-ON REDUCED SCALE FAIRING TESTS

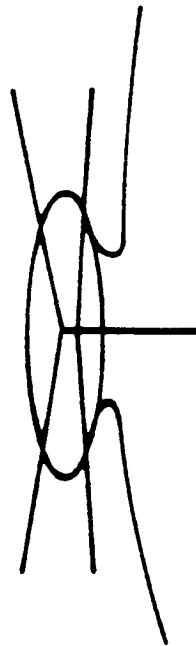
Fwd Fuselage Fairings



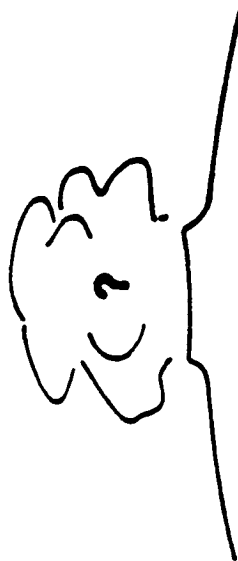
Smaller Lower Fairing with
Faired Shanks



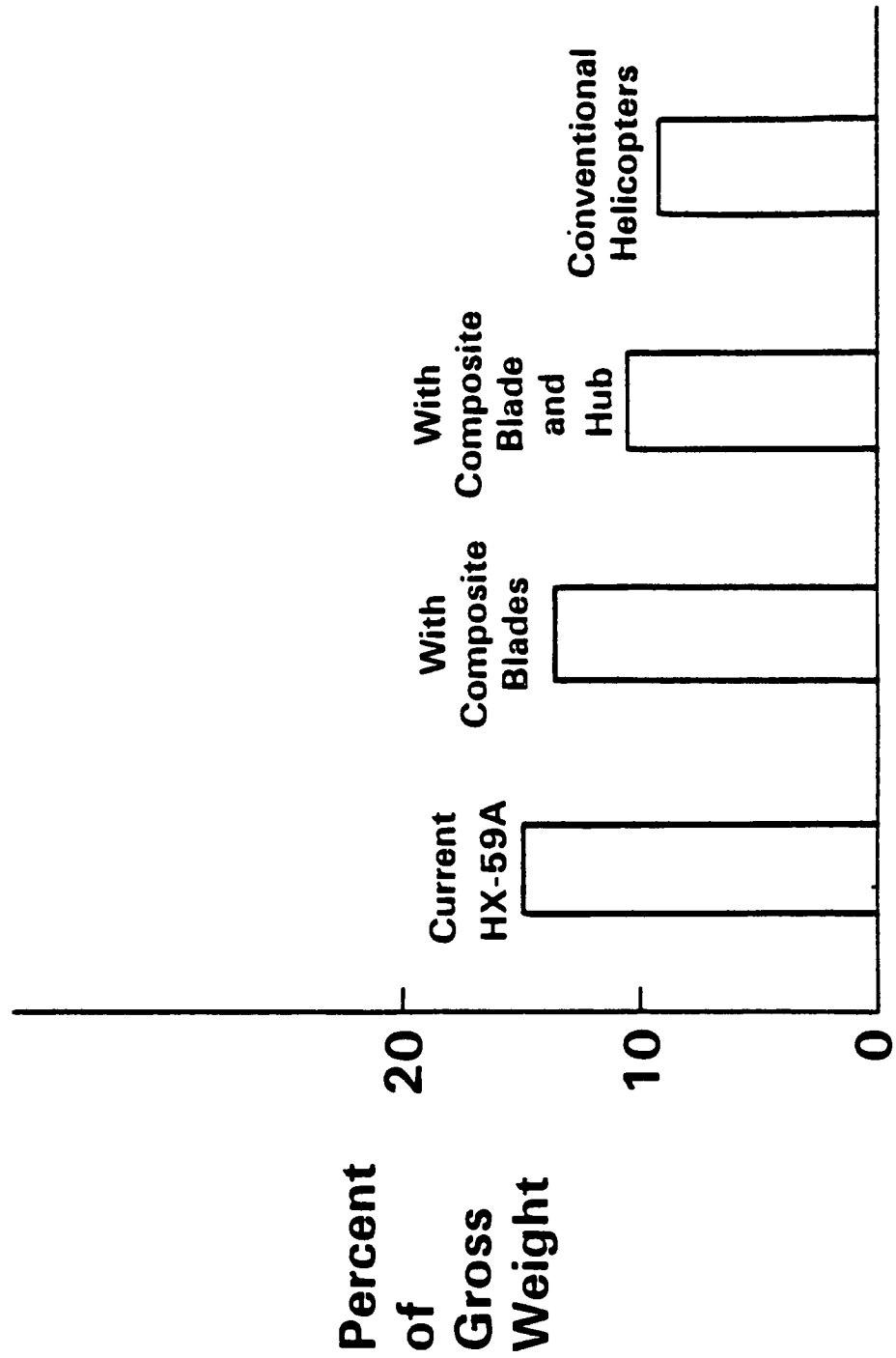
Further Investigation of Rotor Spacing



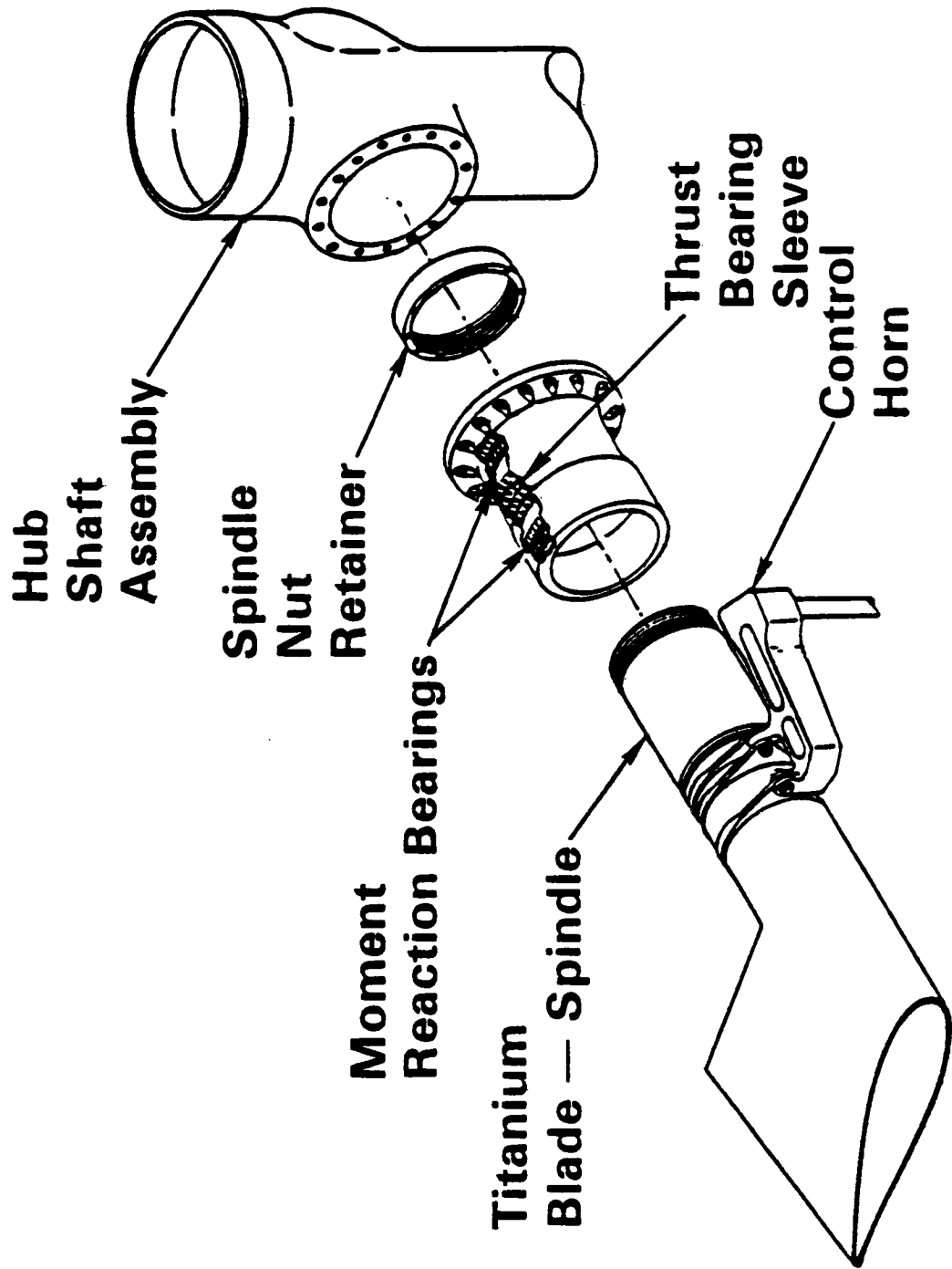
Other Ideas



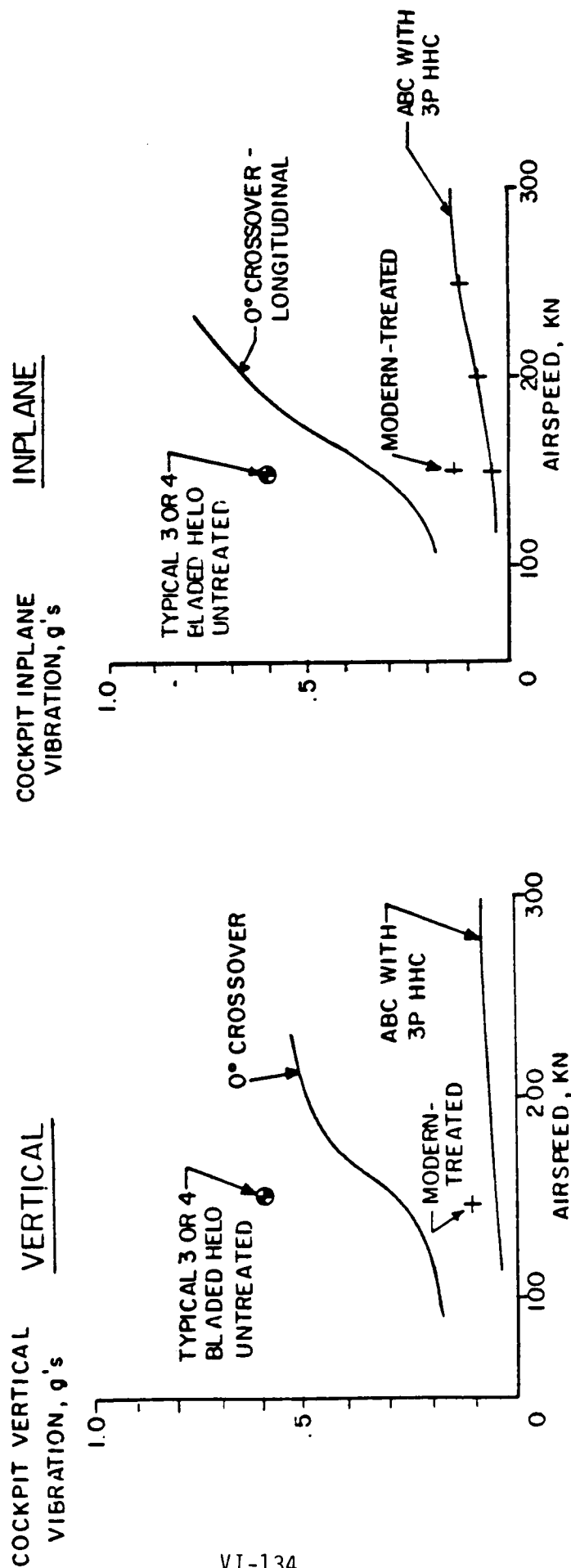
ROTOR WEIGHT REDUCTION



XH-59A ROTOR



ABC COCKPIT 3P VIBRATION REDUCED TO LOW LEVELS WITH HHC



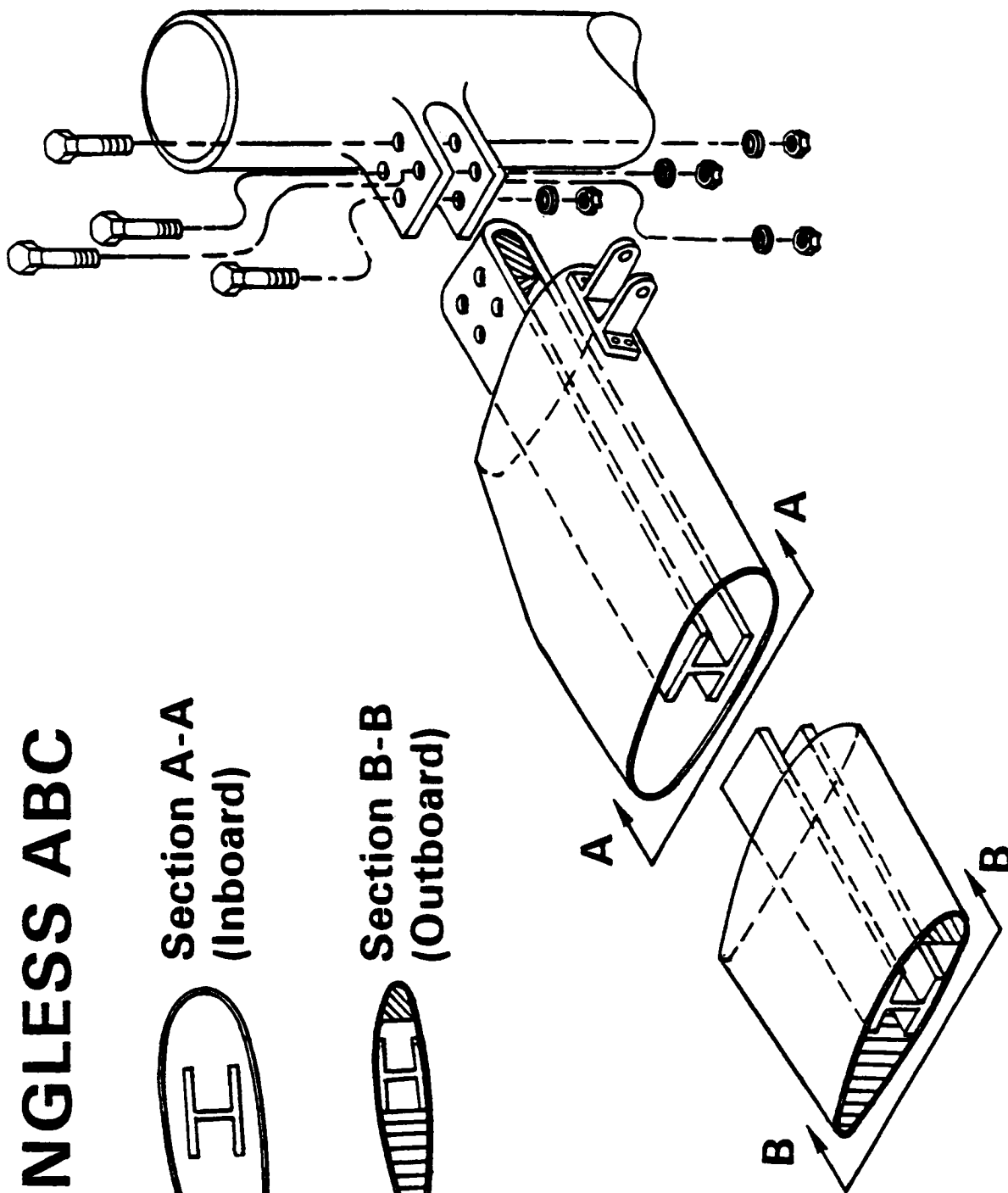
BEARINGLESS ABC



Section A-A
(Inboard)



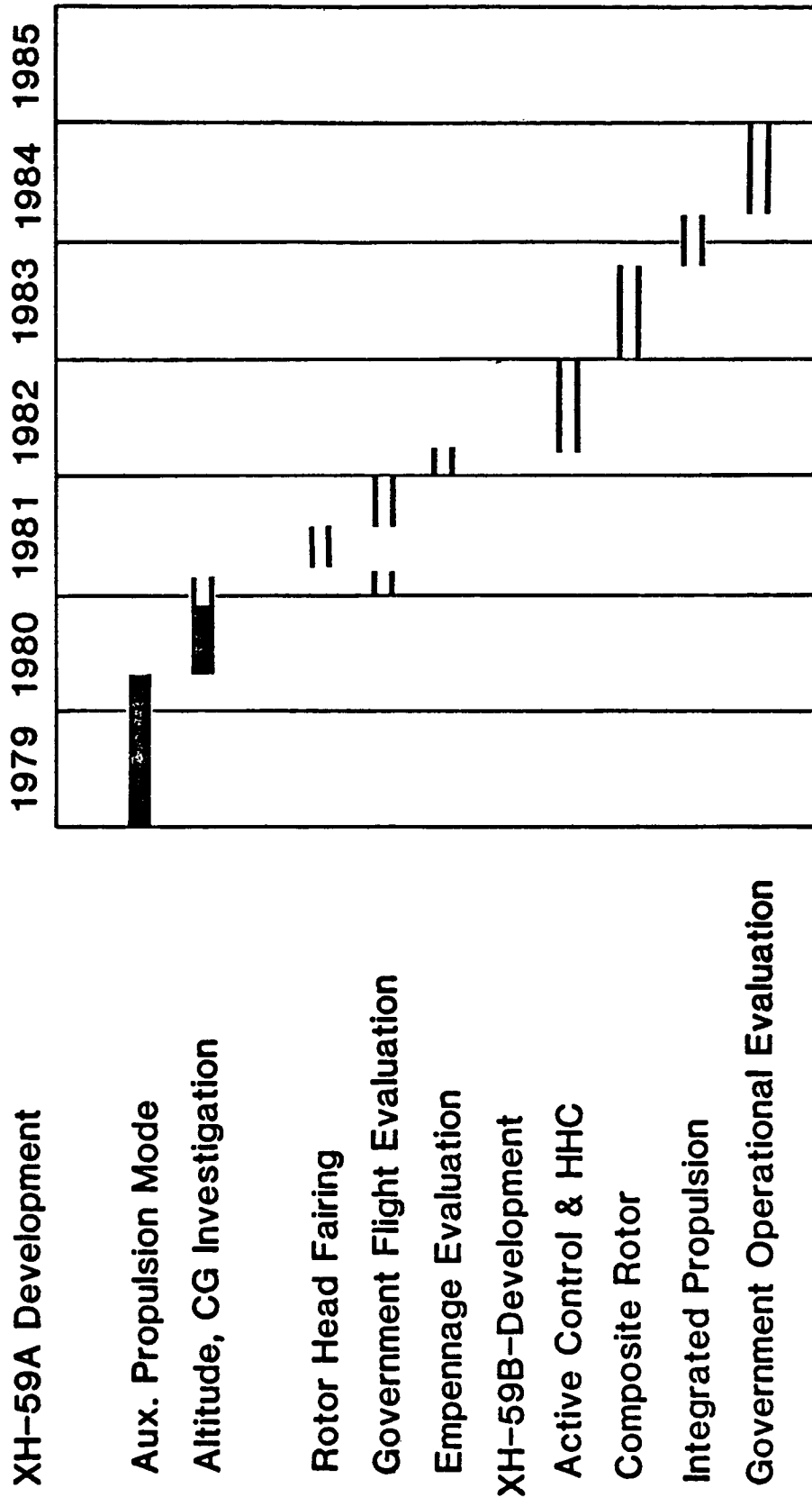
Section B-B
(Outboard)



HANDLING QUALITY AND CONTROL SYSTEM DEVELOPMENT

- **Minimize / Eliminate Empennage**
- **Optimize Control Parameter Scheduling**
- **Minimize Pilot Workload**
- **Optimize Ride Quality**
- **Simplify and Lighten Control System**

ABC DEVELOPMENT PLAN - SUMMARY



ABC CAN BE READY FOR MID-'80'S FULL SCALE DEVELOPMENT



ABC Technology Development Program



User Requirements

- HXM
- Marine AHX
- Air-to-Air (AHH)
- SEMA-X
- Type A V/STOL
- LHX
- Civil Transport
- CSAR



LOW DISC LOADING VTOL AT CRITICAL DECISION POINT

. FLIGHT PROGRAMS ABOUT DONE - TECHNOLOGY BASE FIRING

. NAVY INTEREST EVAPORATING

. ARMY INTEREST MAY BE IMPROVING BUT NO FUNDS YET

. CIVIL MARKET PICTURE BECOMING CLEARER

. NASA FUNDS INSUFFICIENT TO CONTINUE CONSTRUCTIVE FLYING

WHAT'S NEEDED?

- . NASA MUST TAKE LEAD
- . MAKE HIGH SPEED A MAJOR THRUST
- . SELECT MISSION AND ASSESS CONFIGURATION FOR:
 - . MILITARY
 - . CIVIL
- . CONTINUE DEVELOPING TECHNOLOGY REFINEMENTS
 - . WIND TUNNEL
 - . BENCH
 - . SIMULATION
- . THEN MOVE OUT WITH MAJOR PROGRAM FOR SECOND GENERATION TECHNOLOGY DEMONSTRATION

HIGH SPEED HELICOPTER

By

Frank McHugh
Boeing Vertol

During the mid 1970's testing and analytical studies were being conducted to develop a better understanding of the characteristics and limitations to the currently operating rotors. These were supported by wind tunnel tests to substantiate and expand the theoretical trends developed. Blade and control system loads were examined and the correspondence to rotor lift limits was determined. As part of this technology understanding expansion effort, the apparent limitation to high speed operation was examined. Wind tunnel testing was conducted to explore the high speed regime and the results indicated that the conventional rotor has high speed potential.

Configuration studies being conducted at that time integrated the high speed capabilities obtained from this model testing. The VSTOL transport mission being examined to determine the trade-off in gross weight and installed power with design speed indicated the helicopter had the lowest gross weight and power of any of the configurations examined and had a speed range of 180 to 220 kts. This implies the lowest acquisition cost. To determine the effects of the wind tunnel data on operational costs, the 1985 Commercial Transport Study conducted for NASA was upgraded. The effect of cruise speed and drag reduction on direct operating cost was examined. The 1985 commercial helicopter DOC's were reduced by approximately 20% and were closely approaching the level defined for the tilt rotor configuration established by the study. The effect of drag reduction was significant from that of the currently operating helicopters in the same gross weight class; but beyond a level of Gross Weight/Equivalent Flat Plate Area of 1750 lbs/ft² the improvement was small and the difficulty of achieving better levels of drag reduction and the costs are high. The design speed at which the DOC minimizes is approximately 225 knots.

The test data and the studies indicated that the conventional rotor has potential in the high speed regime and indicated we should pursue the following areas of research and development:

- Improved rotor performance
- Increased speed potential
- Drag reduction
- Light weight structure

What should be the next step? After carefully considering the four major areas of research and development, Boeing Vertol decided that we first must:

- Determine the high speed boundaries of the conventional rotor
- and
- Define the areas of highest drag reduction potential.

NASA was also interested in determining the lift and propulsive force boundaries of a rotor in high speed flight. This led to a joint effort between NASA and Boeing Vertol to conduct a wind tunnel test of a model rotor. Rotor performance, control loads and lift limits were determined out to 225 knots. This testing demonstrated that the conventional rotor can operate in high speed forward flight at useful levels of lift without auxiliary lift or auxiliary propulsion.

As part of NASA's research, a study was conducted to determine the payoff in fuel reduction resulting from estimated levels of improvement potentially available from advanced technology. The three major improvements were light weight structure, rotor lift/effective drag ratio and hover figure of merit in addition to regenerative engines. The combined improvement of all the technology improvements was 30 to 40 percent. To determine which of the technologies would provide the largest fuel saving per dollars spent in development, an additional study was made to access the cost of research and development required to provide the level of technology improvement used in the study. Drag reduction provided the largest fuel saving per development dollar with figure of merit and rotor lift/effective drag ratio as the next two major areas. Light weight structure and engine development were assessed, at that time, as having high development costs and thereby provide low energy savings per development dollar.

These programs reinforced the direction that Boeing Vertol had selected - development of the improved rotor and drag reduction - as being the most cost effective from the energy saving per development dollar. We established our near term objective as: Develop an advanced rotor to operate efficiently at 180 knots. The first step was to determine analytically the airfoil requirements at 180 knots over the total rotor disk in terms of maximum lift and drag divergence. Having established the requirement, the airfoil contour could then be defined. The upper surface is defined to meet the maximum lift; the lower surface is defined by drag divergence and camber is defined by hover performance requirements. The final constraint is to provide these characteristics with a pitching moment coefficient of approximately zero for control load alleviation. The resulting airfoil is our third step in the continuing development of cambered airfoils for helicopters. The first step was incorporated in the CH46 and the second is currently on the CH47D. The 2-dimensional test data obtained for the airfoils indicated that they met or exceeded the requirements and a rotor was designed and fabricated incorporating these airfoils to substantiate the rotor characteristics. This testing proved very successful and the resulting performance was used to estimate full scale performance. There was approximately a 10 percent improvement in hover performance and a 60 percent improvement in forward flight in conjunction with 50 knot increase in speed over a rotor using the 23010 airfoils.

Drag reduction has been explored to define the areas of greatest potential; airframe, landing gear, rotor hub, and miscellaneous protuberances were defined. Drag reduction targets were established and the continuing effort has been directed toward these items. The reductions in drag are reflected in the increasing gross weight/equivalent flat plate area ratio and are shown in the rotary/wing transport helicopter trend with time.

Improvements in hover and forward flight rotor performance and drag reduction are only two of the technology advancements that have been developed since the mid 1970's. Improvements in composite technology have led to greater utilization in helicopter fabrication. The results have led to strong, light weight structures with a significant increase in fatigue characteristics. Advances in engine technology have demonstrated substantial decreases in specific fuel consumption that show corresponding reductions in fuel consumption.

These technology advancements have been developed recently and they can significantly reduce fuel consumed or improve fuel efficiency. The sum of the projected individual improvements amounts to approximately 35% but when combined the advancements provide approximately 50% gain in fuel efficiency. Translating this reduction in fuel consumed into a reduction in direct operating cost provides approximately 40 percent reduction in cost per seat mile.

The next step and Boeing Vertol's long term goal is to develop an advanced rotor to operate efficiently at 225 knots that is light weight, simple to build and has acceptable vibration and noise characteristics. This advanced rotor must have performance at 225 knots similar to that of the near term rotor operating at 180 knots. In conjunction with the improved performance the cabin vibration levels must not be any worse than that currently demonstrated by the Model 234 at 150 knots. To achieve these further advancements in technology will require an extensive research and development program of the rotor and airframe that must be supported by NASA. This research is required to expand the existing understanding of the rotor aerodynamic and aeroelastic characteristics and requirements, for the industry to be postured to design a high speed helicopter satisfactorily. The elements of the recommended research are:

- Develop high speed airfoil requirements.
- Define airfoil contour for high speed.
- Determine geometry and structural definition of high speed rotor.
- Fabricate model to complete high speed rotor development.
- Finalize rotor definition.

- Design, fabricate and test full scale high speed rotor.

Implementation of this effort now will provide an efficient high speed rotor with low vibration and noise in the mid to late 1980's.

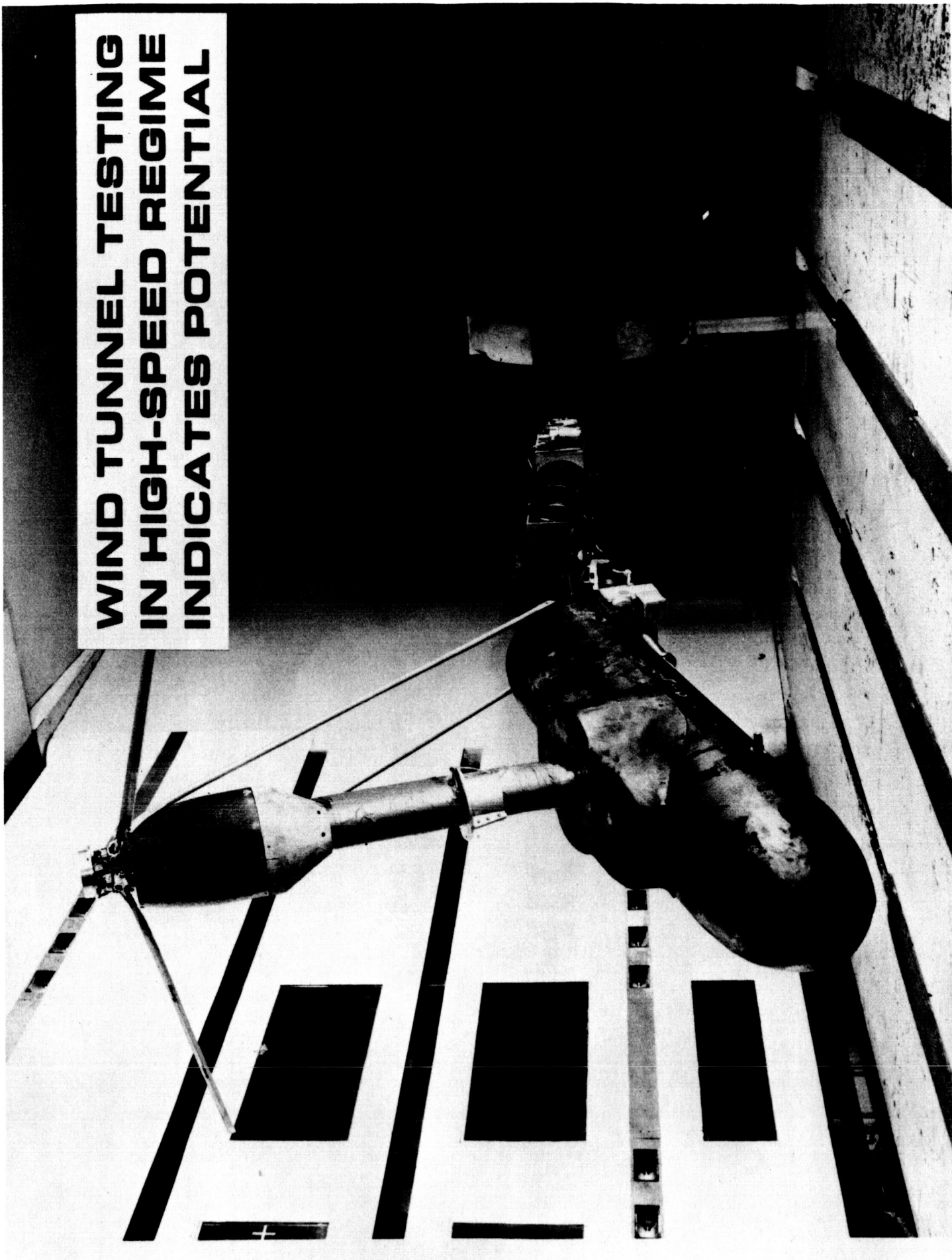
BIOGRAPHY

Frank McHugh
Manager of Aerodynamics and Advanced Rotor Technology
Boeing Vertol Co.

Frank McHugh has continuously supported or managed programs at Boeing Vertol to expand the operational flight regime of V/STOL aircraft; such as: the high speed helicopter, tilt rotor, compound and other advanced rotor concepts. He has also conducted successful exploratory development of active and passive means of effectively reducing vibratory hub loads to provide a usable high speed operational regime.

HIGH-SPEED HELICOPTER

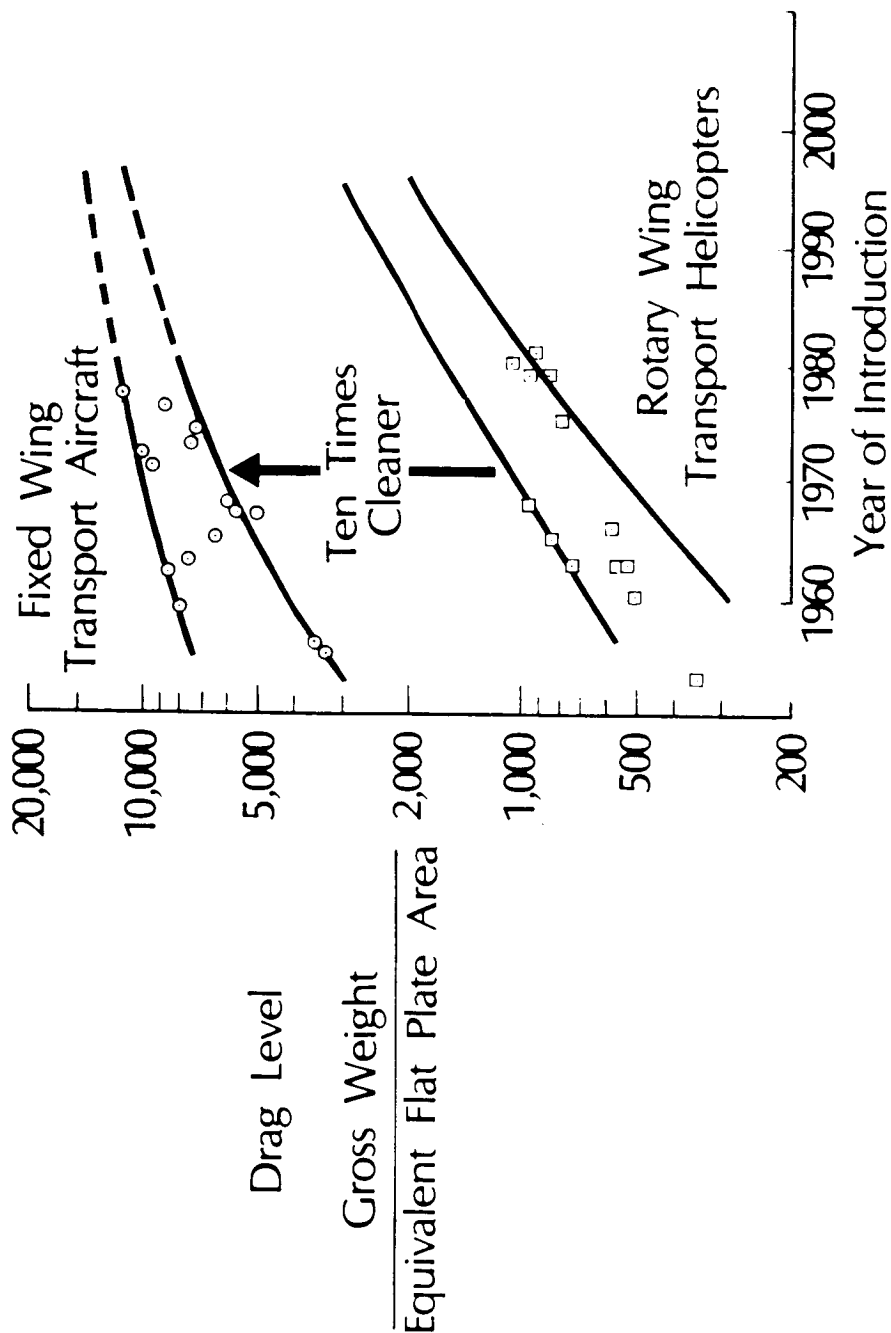
**WIND TUNNEL TESTING
IN HIGH-SPEED REGIME
INDICATES POTENTIAL**



VI-148

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

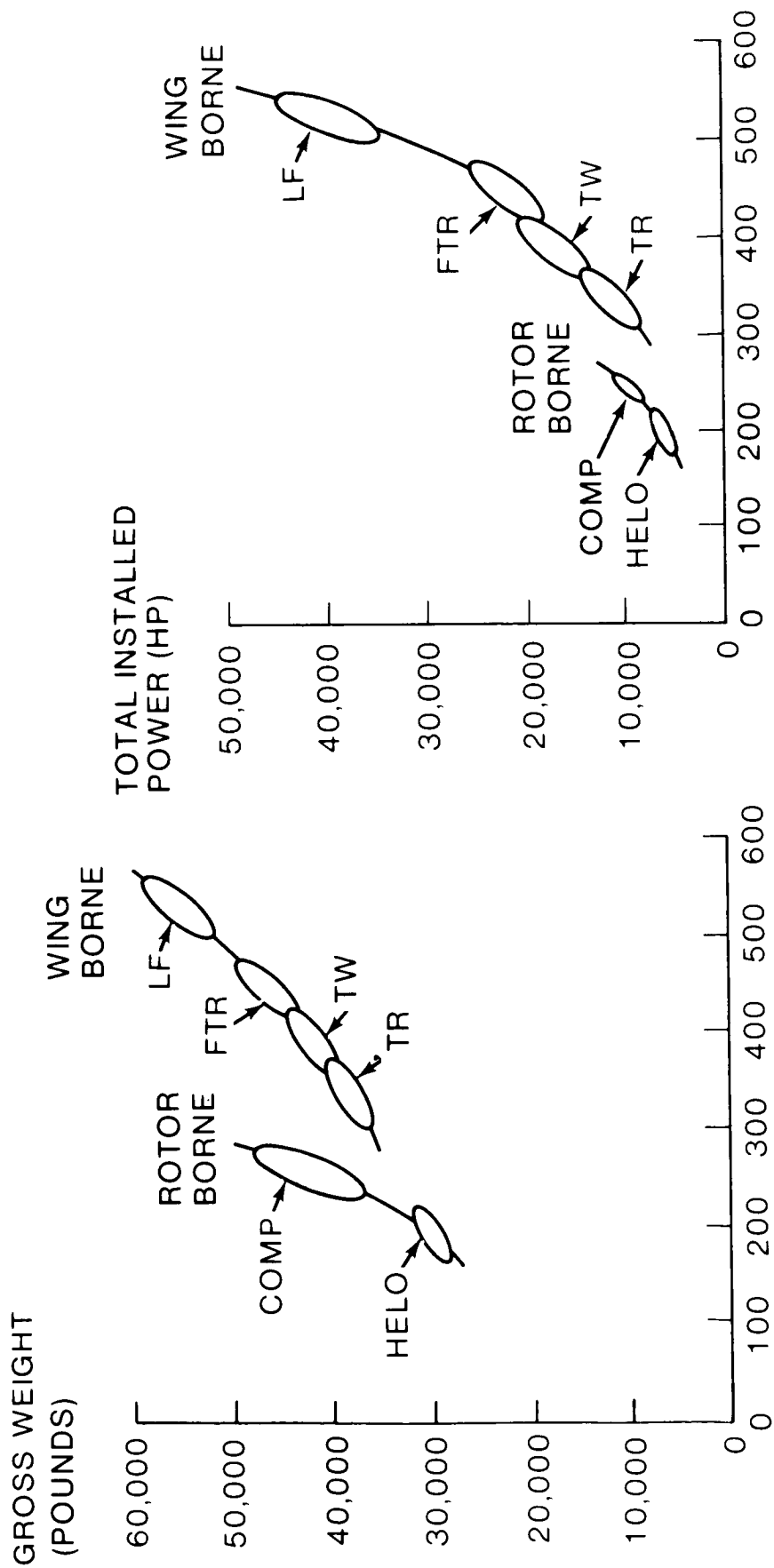
AIRFRAME DRAG TREND



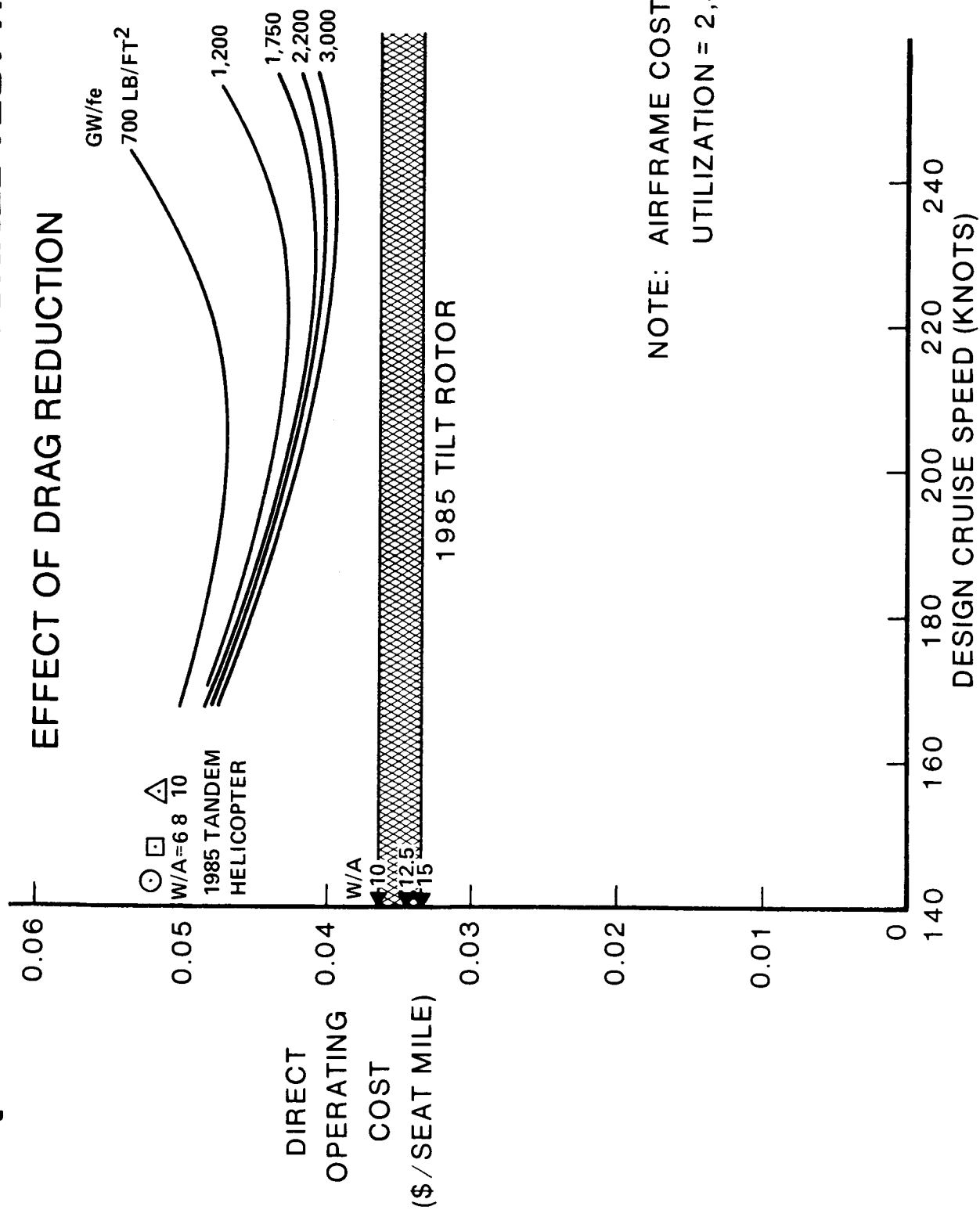
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CONFIGURATION STUDY

DIRECT RELATIONSHIP OF SIZE TO SPEED



COMMERCIAL TRANSPORT STUDY UPGRADED [MODIFIED WITH HELICOPTER WIND TUNNEL TEST RESULTS]



CONCLUSION

- PURE HELICOPTER HAS POTENTIAL IN HIGH-SPEED REGIME

PURSUE

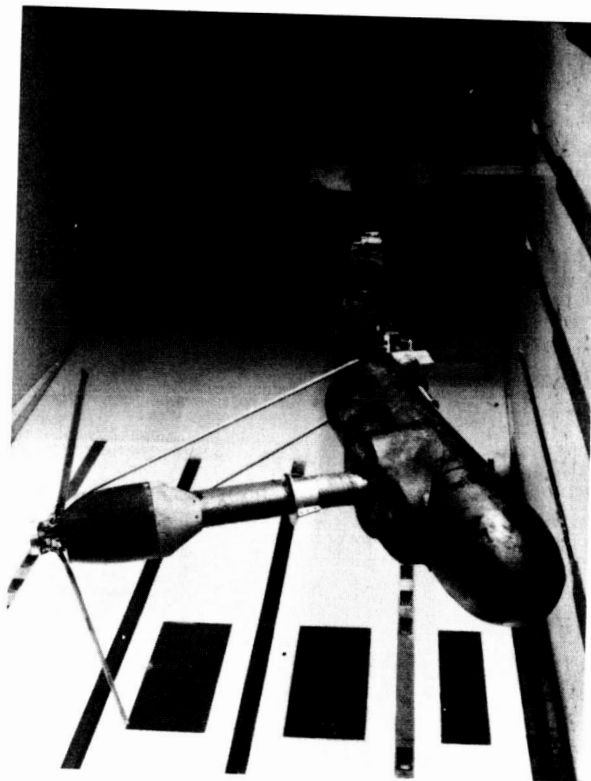
- IMPROVED ROTOR PERFORMANCE
- INCREASED SPEED POTENTIAL
- DRAG REDUCTION
- LIGHTWEIGHT STRUCTURE

NEXT STEP

- DETERMINE HIGH-SPEED BOUNDARIES OF CONVENTIONAL ROTOR
AND
DEFINE AREAS OF DRAG REDUCTION POTENTIAL

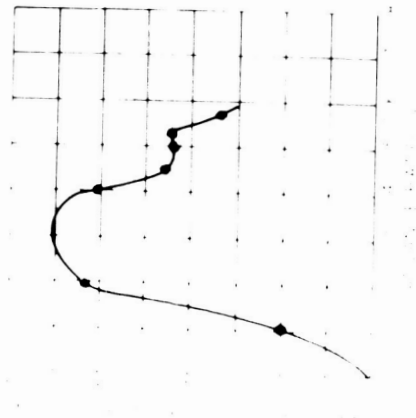
1977 NASA SPONSORED MODEL TESTING DEMONSTRATES

THE CONVENTIONAL ROTOR CAN OPERATE IN HIGH-SPEED FORWARD FLIGHT AT USEFUL LEVELS OF LIFT WITHOUT AUXILIARY LIFT OR AUXILIARY PROPULSION



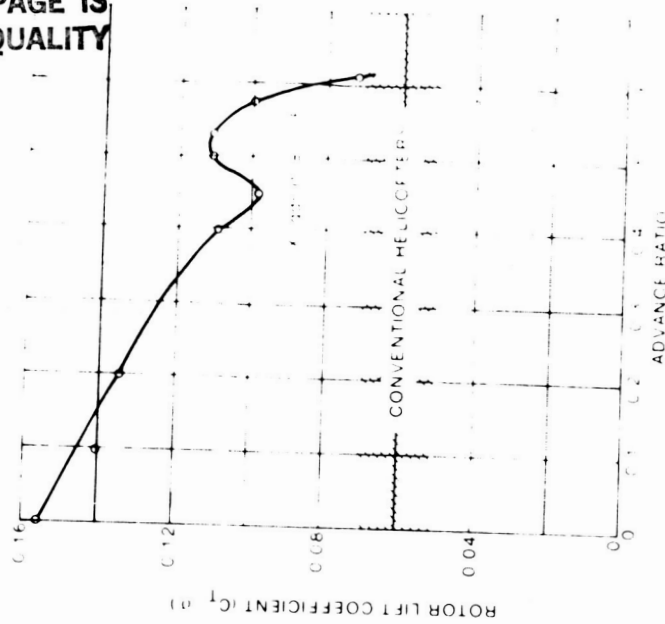
PERFORMANCE

$C_t = 0.06$

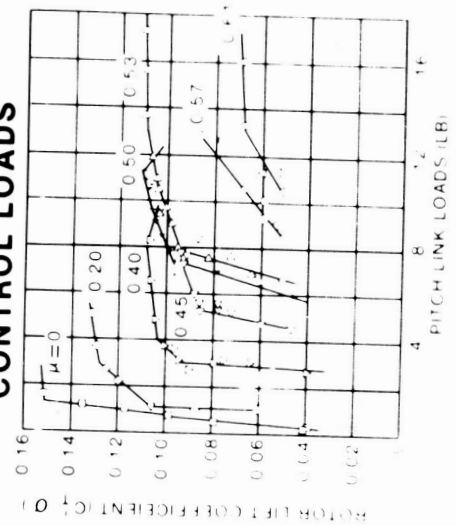


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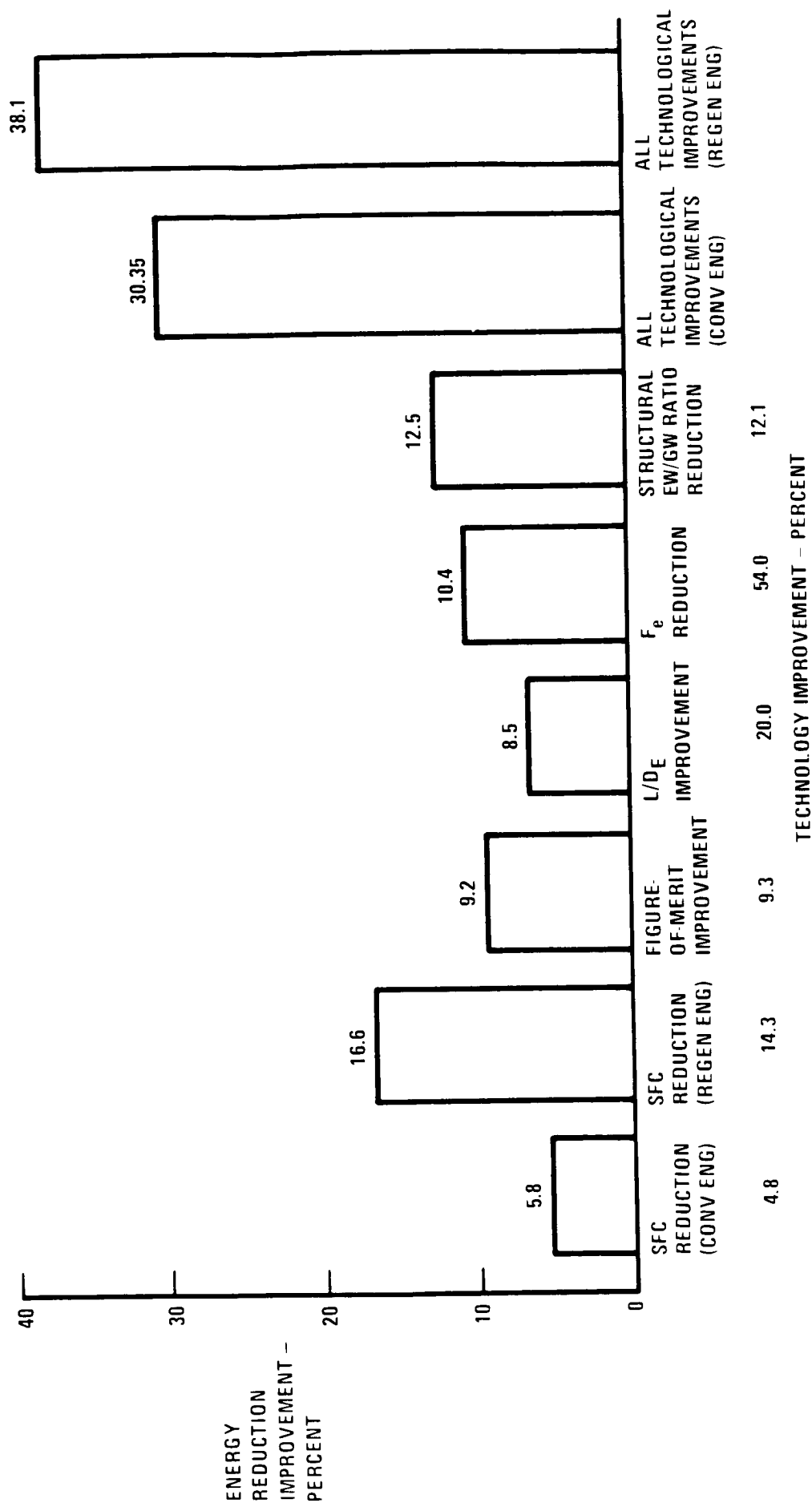
LIFT LIMITS



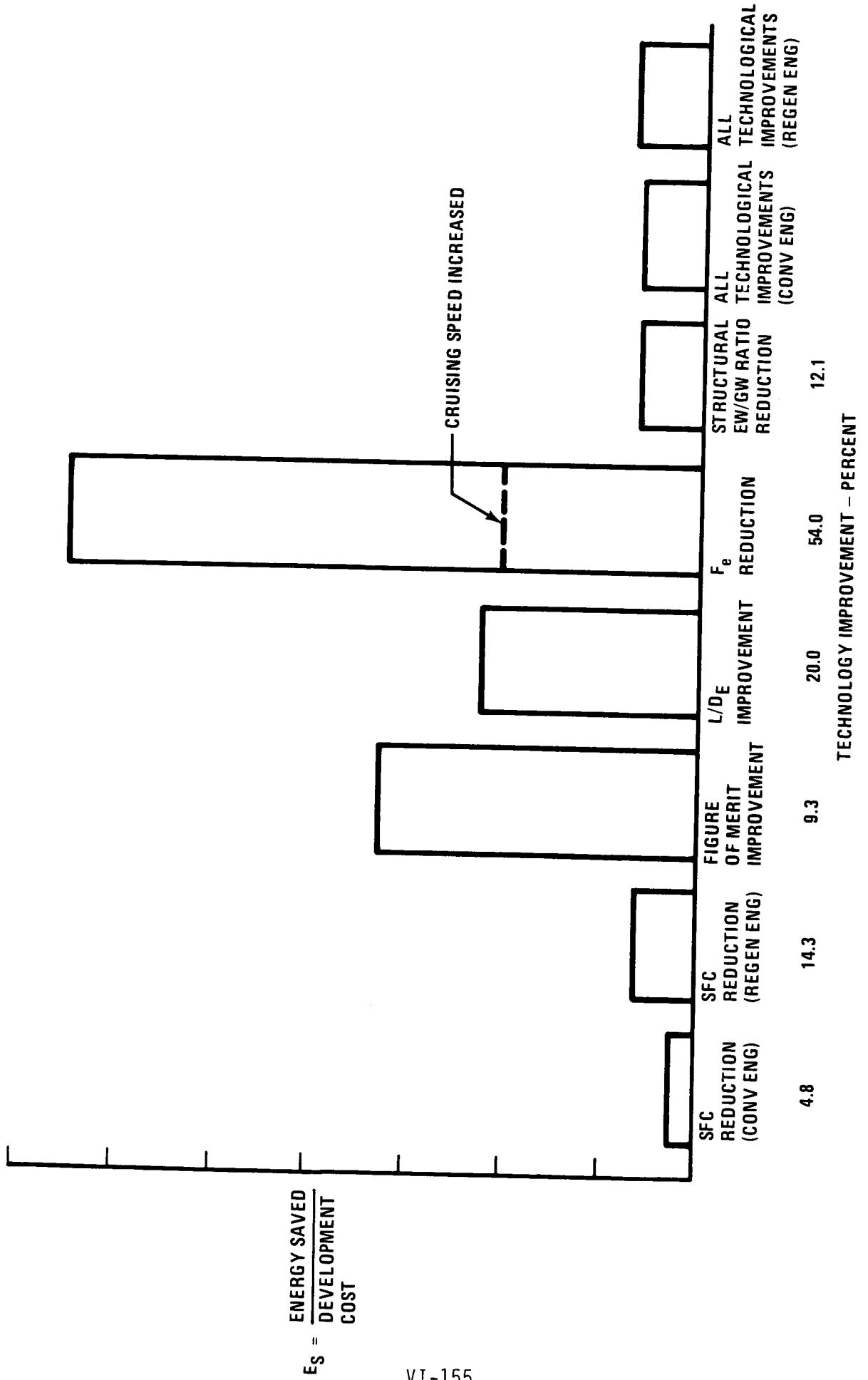
CONTROL LOADS



1977 NASA SPONSORED STUDY OF ADVANCED TECHNOLOGY FEATURES FOR REDUCING FUEL CONSUMPTION



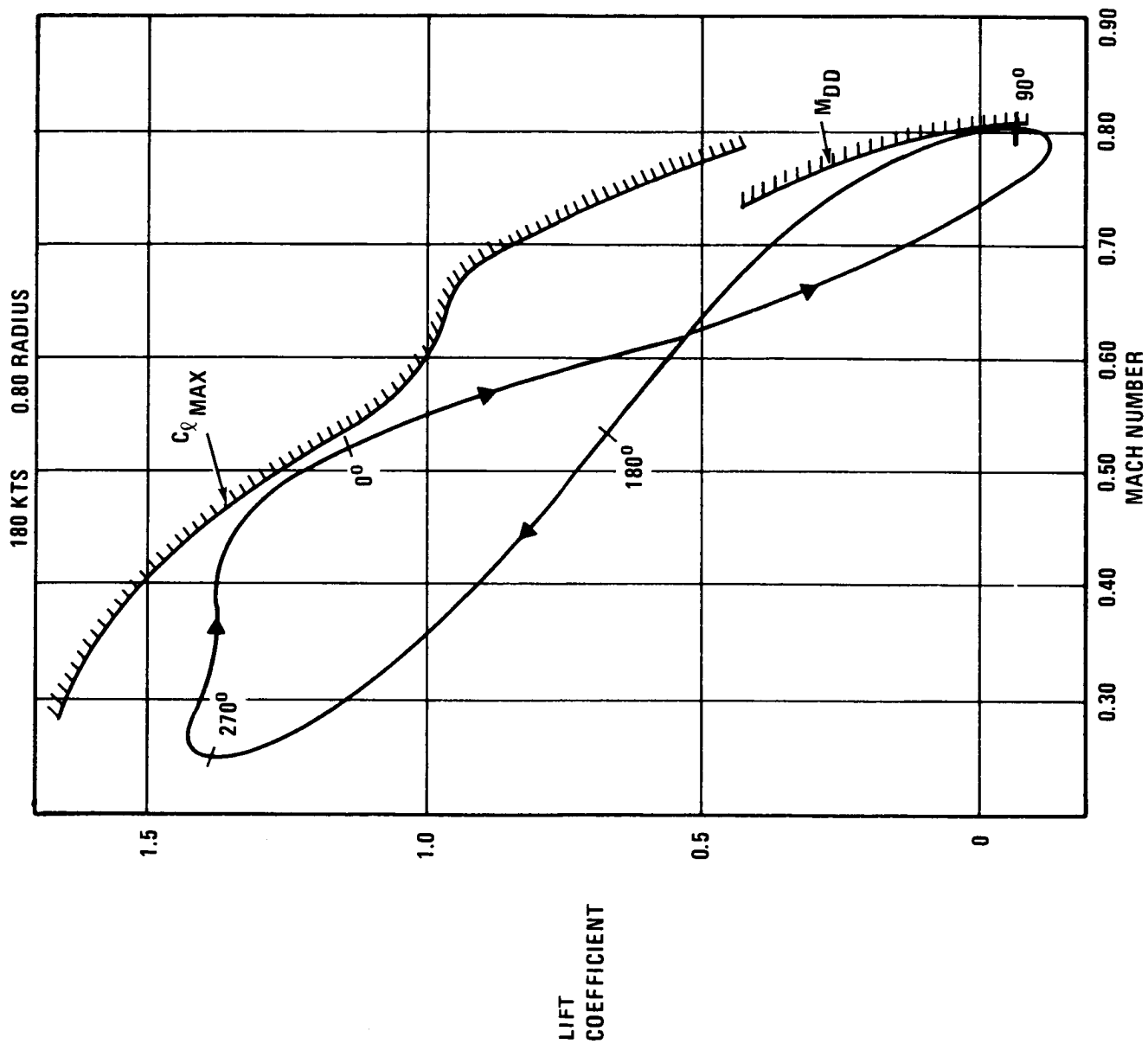
1977 NASA SPONSORED STUDY ESTABLISHED COMPARISON OF PAYOFFS IN HELICOPTER ENERGY RESEARCH



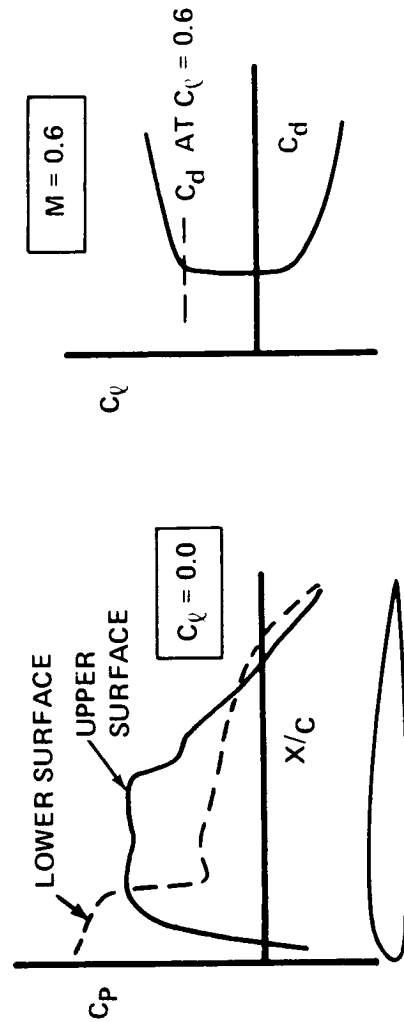
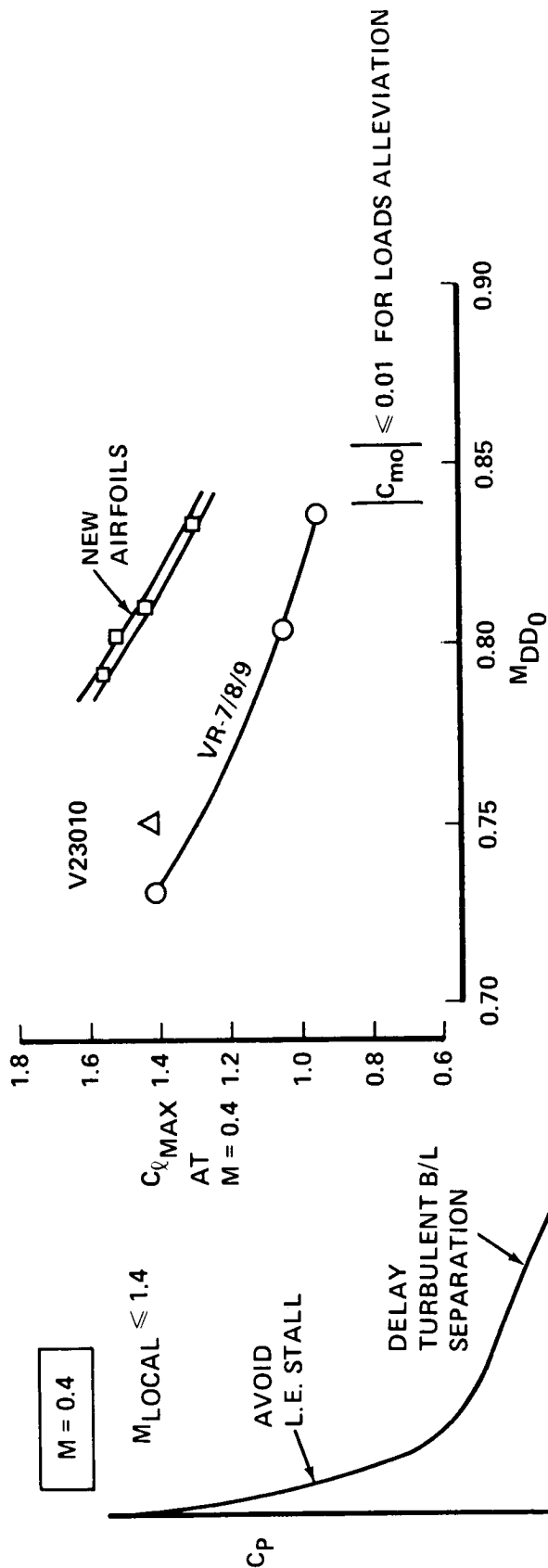
NEAR TERM OBJECTIVE

**Develop an Advanced Rotor to
Operate Efficiently at 180 Knots**

DEFINED AIRFOIL REQUIREMENTS AT HIGH SPEED



ADVANCED AIRFOIL DESIGN PROCEDURE



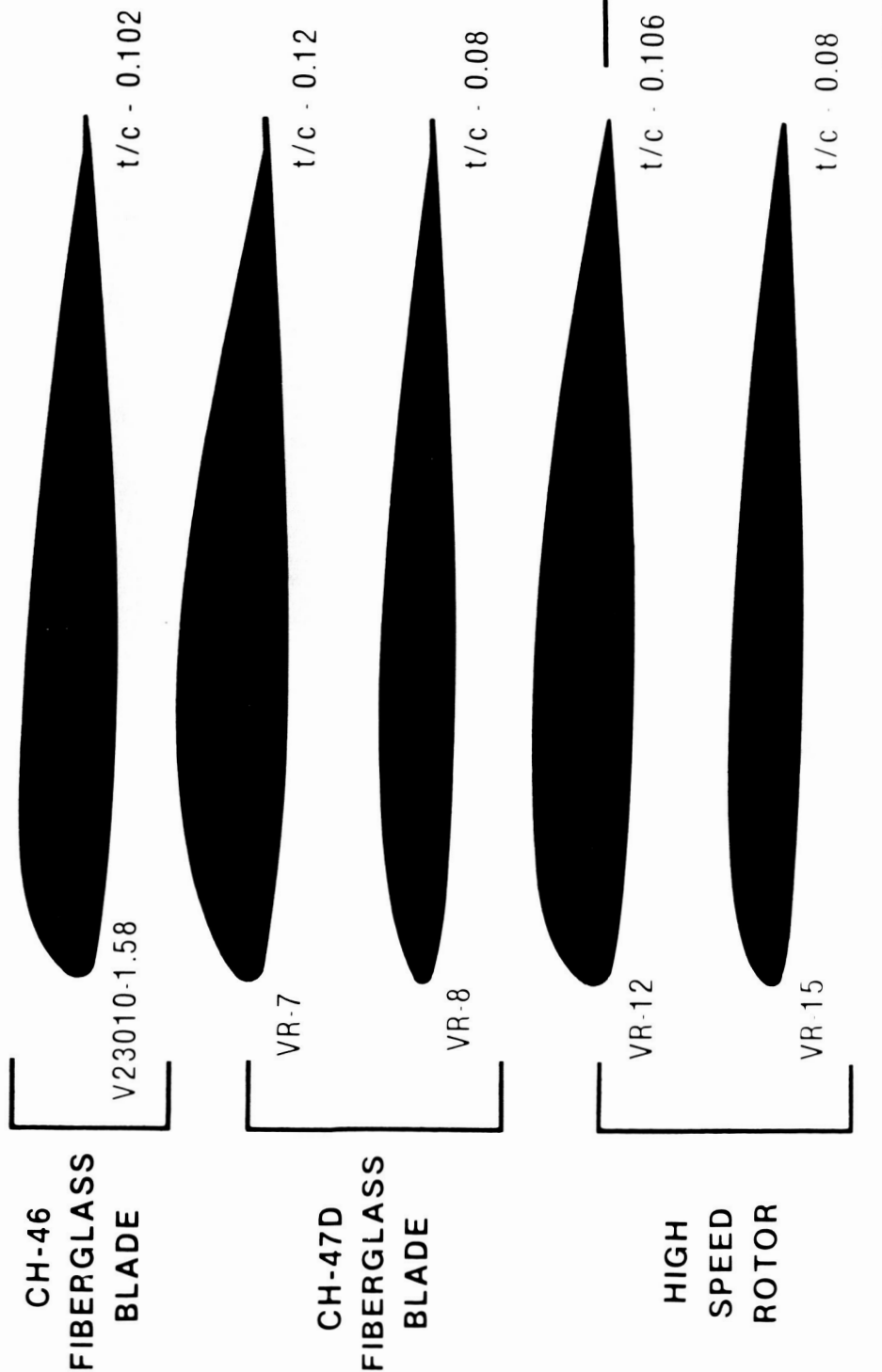
• UPPER SURFACE DESIGNED FOR $C_{\ell MAX}$

• LOWER SURFACE L.E. DESIGNED FOR DRAG DIVERGENCE

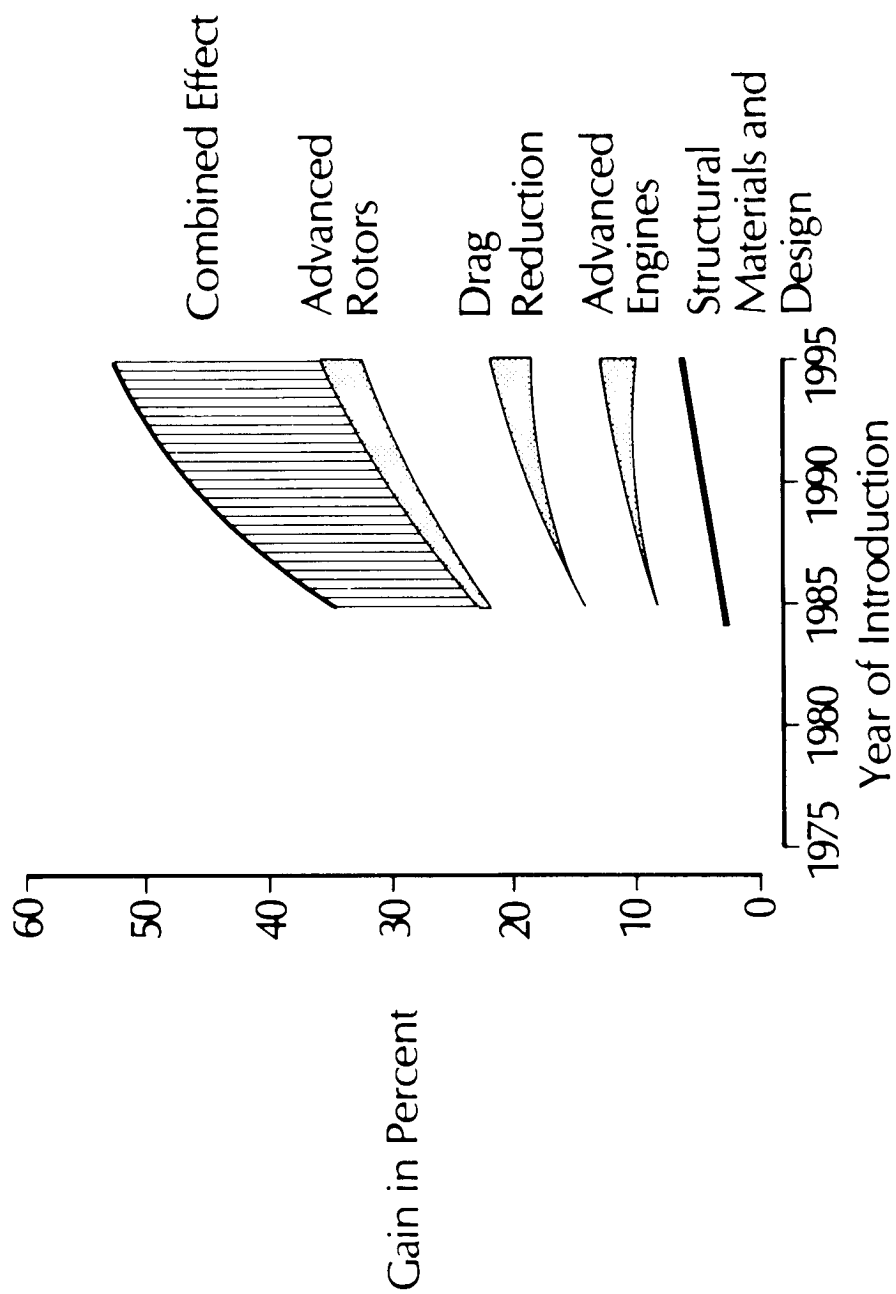
• CAMBER LEVEL SELECTED FOR HOVER PERFORMANCE

BOEING VERTOL HELICOPTER AIRFOIL DEVELOPMENT

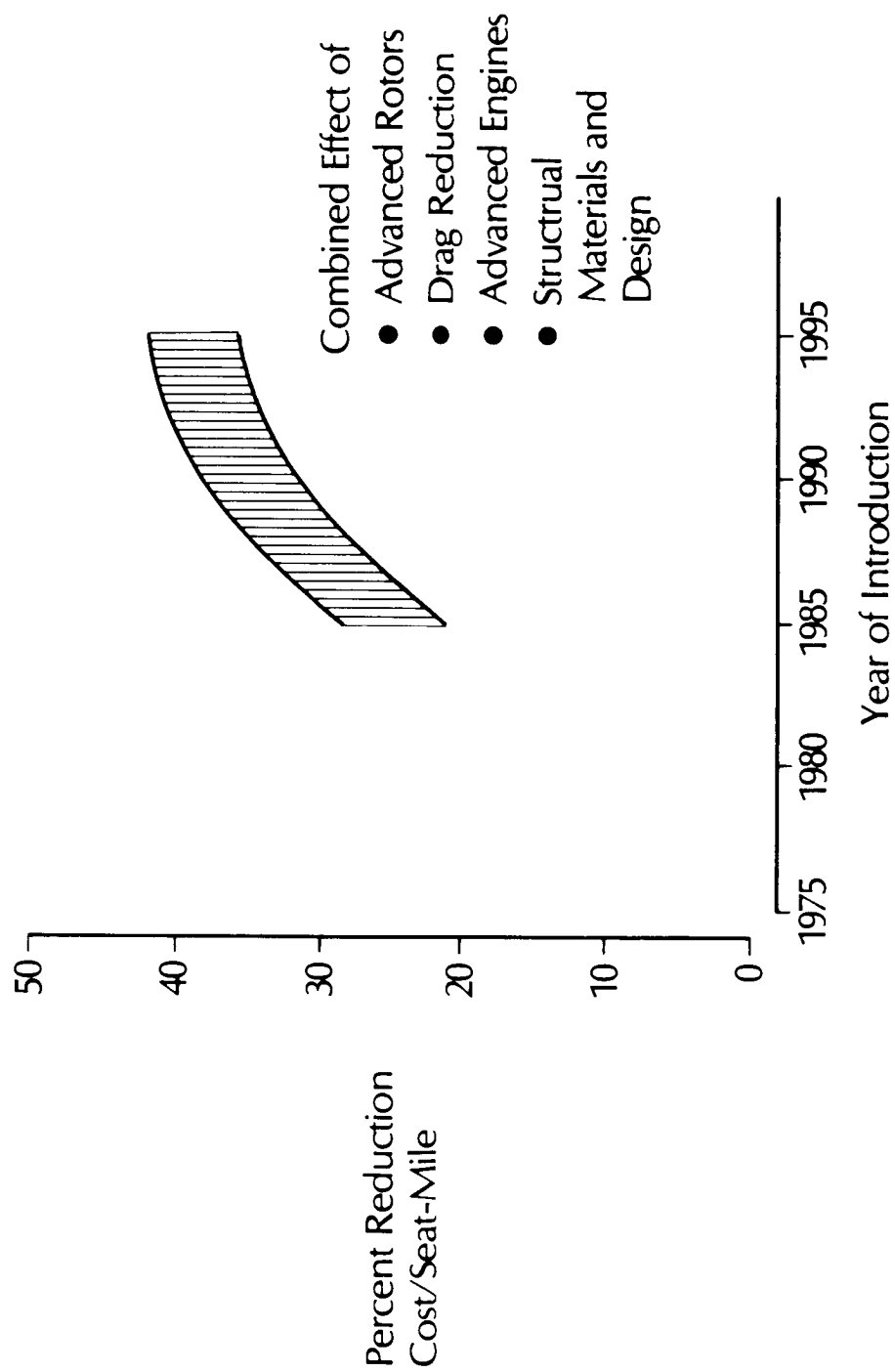
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FUEL EFFICIENCY



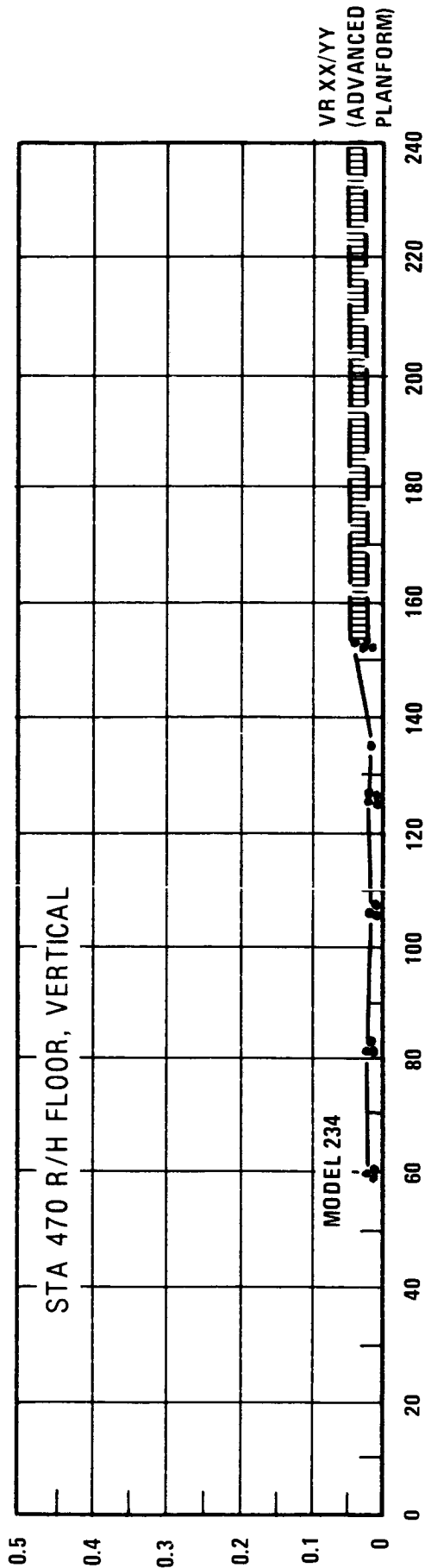
REDUCED DIRECT OPERATING COST



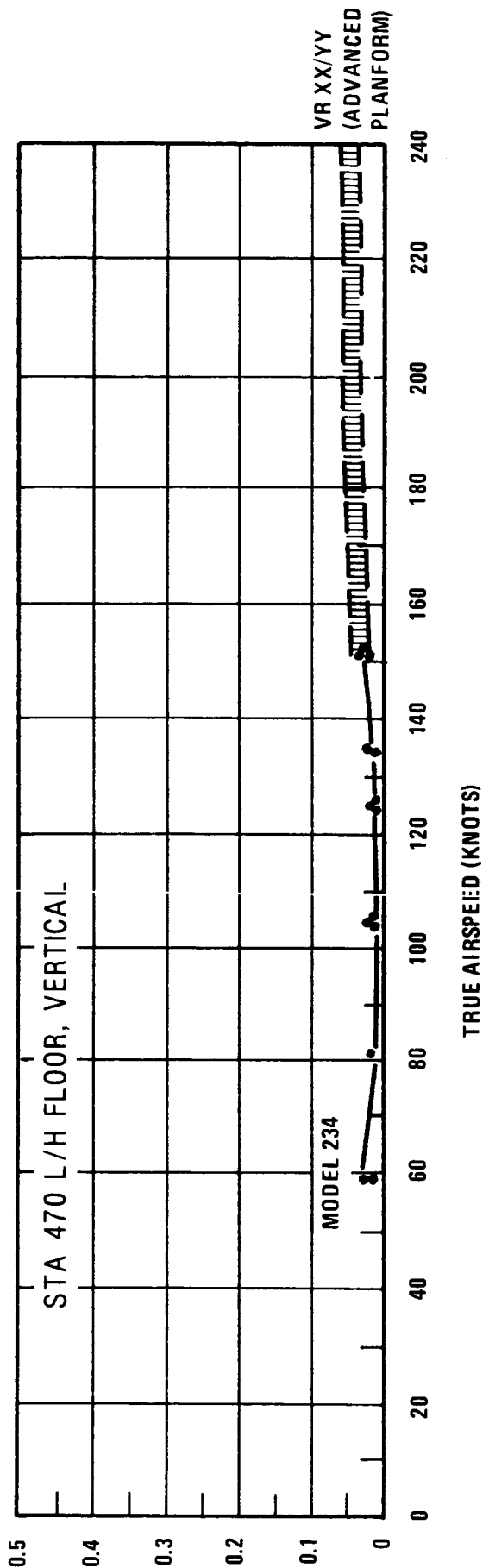
LONG-TERM OBJECTIVE

**Develop an Advanced Rotor to
Operate Efficiently at 225 Knots
That is Lightweight, Simple to Build and
has Acceptable Vibration and Noise
Characteristics**

CABIN VIBRATION LEVELS



VI-163



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RESEARCH REQUIRED TO ACCOMPLISH LONG-TERM OBJECTIVE

- Develop High-Speed Airfoil Requirements
- Define Airfoil Contour for High Speed
- Determine Geometric and Structural Definition of High-Speed Rotor
- Fabricate Model to Complete High-Speed Rotor Development
- Finalize Rotor Definition
- Design, Fabricate and Test Full-Scale High-Speed Rotor

LARGE ROTORCRAFT VEHICLE CONFIGURATIONS SUBSESSION

TECHNOLOGY FOR MULTILIFT

By

E. S. Carter
Sikorsky Aircraft

The potential of harnessing two or more helicopters to the same payload has come up for consideration a number of times. Initially, it was regarded as a means of providing the ability to carry military loads which could not be broken down and were beyond the capacity of the largest helicopters in service, but more recently its potential for extending the capabilities of medium payload civil helicopters has been suggested because of the very high cost of ferrying the relatively few heavy lift civil helicopters to a given location for an occasional heavy lift. It would appear to provide a useful means for the more economical bidding of a job with a small amount of heavy lift requirement in an area where crane helicopters are not already operating. In fact, ingenious operators have already used the technique to a limited degree as for instance, the Heli-Ecuador cable-carrying example in Ecuador.

Serious investigation of multi lift have been sponsored by the Department of Defense at least twice. In the early 1960's, the Army contracted with Boeing Vertol for a hardware demonstration but this was terminated when technical feasibility was questioned by senior Army commands. Later in 1968, Sikorsky was funded for additional studies of possible techniques and these studies did in fact result in a demonstration of a 20-ton twin lift using two CH-54 helicopters in 1970.

These studies considered many options and, like the Boeing work, selected the spreader bar configuration shown in Figure 2. Optimum geometry for a manual controlled solution was developed. The demonstration confirmed feasibility of air taxi operations for short distances but pilot workload was high and it was not deemed feasible to transition to significant forward velocities without more pilot unburdening.

This led to the proposal of a "master-slave" automatic control concept by which a command pilot in one helicopter would essentially fly the formation by appropriate manipulation of his helicopter while the slave helicopter was automatically controlled to maintain spreader bar orientation both in elevation and azimuth and to maintain separation. It was pointed out that all necessary sensing could be derived from cable angle sensing and spreader bar altitude and azimuth and that slave control algorithms and stability consideration would be very similar to those successfully managed in the Navy Sonar couplers. Unfortunately, funding for a demonstration of this approach aborted when the U. S. Army decided to put all its heavy lift priority development resources into the HLH program.

Now, with the heavy lift helicopter "an unaffordable requirement" and with the great advances that have been made in digital control technology, it is most timely to reconsider a demonstration program.

Two aspects should be investigated - First, the master slave control solution should be demonstrated and secondly, technology to reduce the weight and increase the transportability of the spreader bar should be supported.

A possible program for NASA master slave control demonstration would consist of:

1. Reactivation of the external lift simulation capability developed some years ago by the Langley Research Center, and its extension to the twin lift situation probably at the Ames Research Center.
2. Use of this simulation, first to explore possible control law options and then to debug flight-worthy digital flight control hardware.
3. A flight program on an available medium size helicopter, preferably one with a well developed digital flight control system and good control power. This program could consist of a gradual build up of:
 - . Slave helicopter hover tether tests to confirm initial stability limits.
 - . Slave helicopter hovering tests on one end of a spreader bar with the other end suspended from a ground based high point.
 - . Master slave hover tests using any well stabilized good control power helicopter as the master.
 - . Gradual transition to forward flight and eventually into coordinated turns.

4. Spreader bar structural optimization studies would consist of concept development of foldable spars using composite materials. It is anticipated that eventually it should be possible to build a spreader bar for 5 % of the weight of the payload.

MULTILIFT NEEDS

HAA/NASA WORKSHOP

E. S. CARTER

SIKORSKY AIRCRAFT

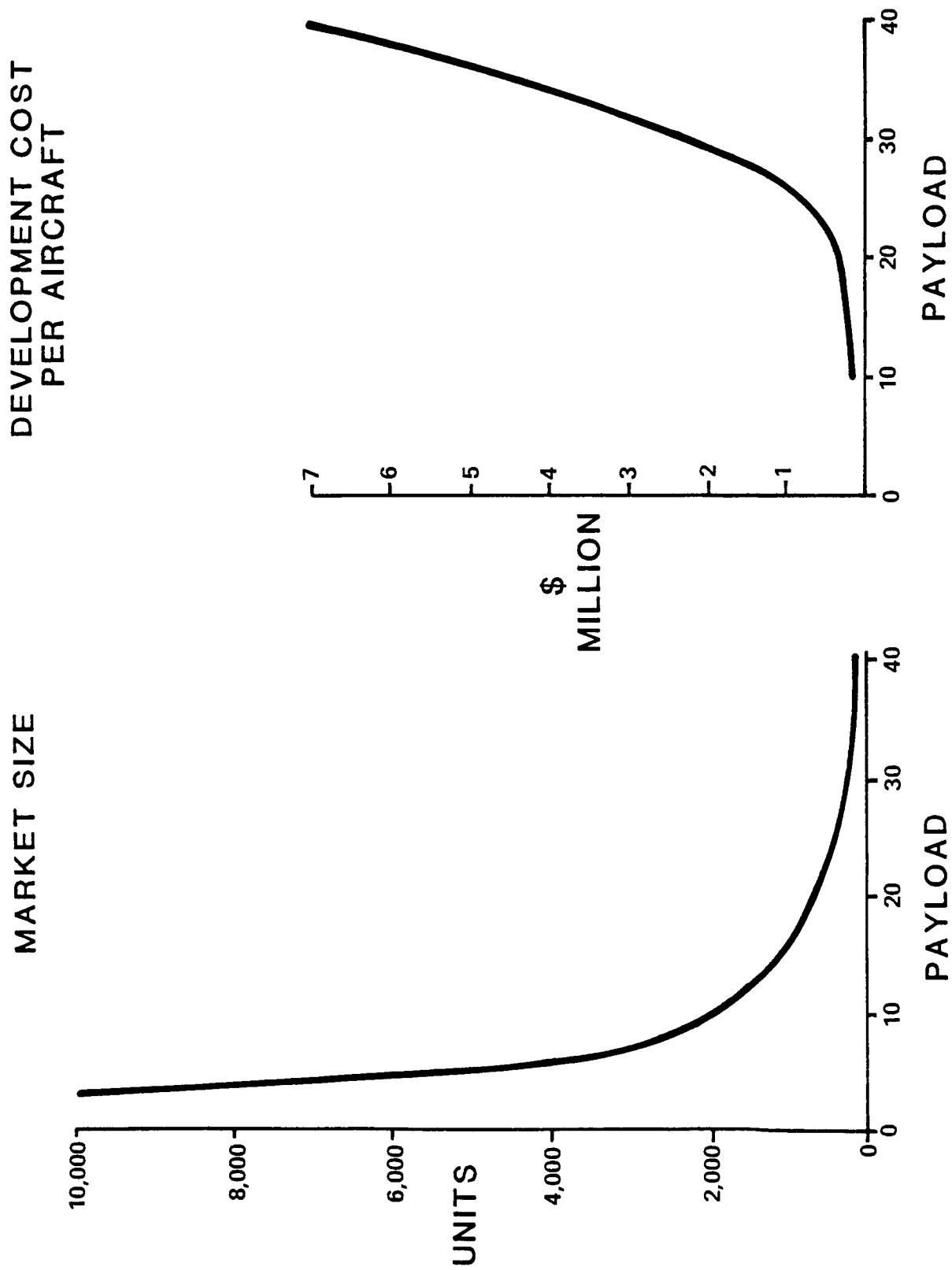
REASON TO CONSIDER TWIN LIFT

. OCCASIONAL LOADS BEYOND CAPACITY OF

. LARGEST HELICOPTERS

. LARGEST HELICOPTER IN THE AREA

ECONOMIC PROBLEM OF HEAVY LIFT



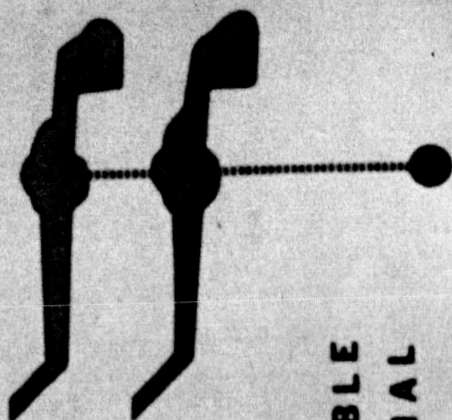


TWO HELICOPTERS CARRYING CABLE

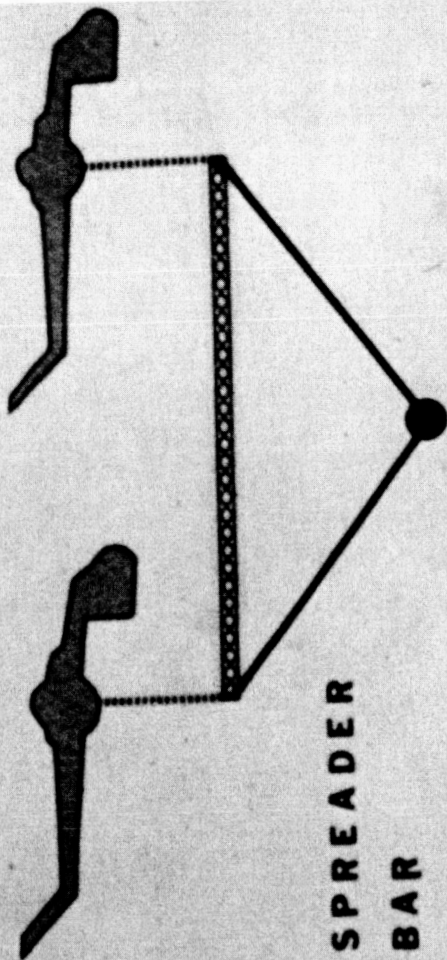
VI-171

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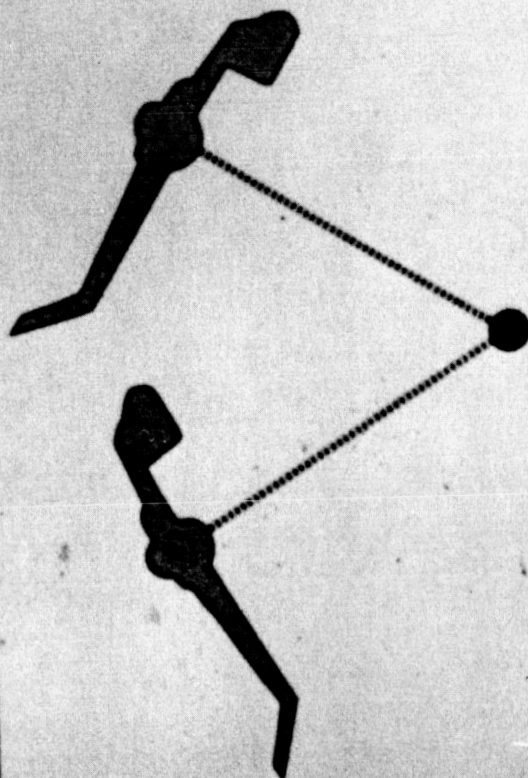
CANDIDATE CONFIGURATION



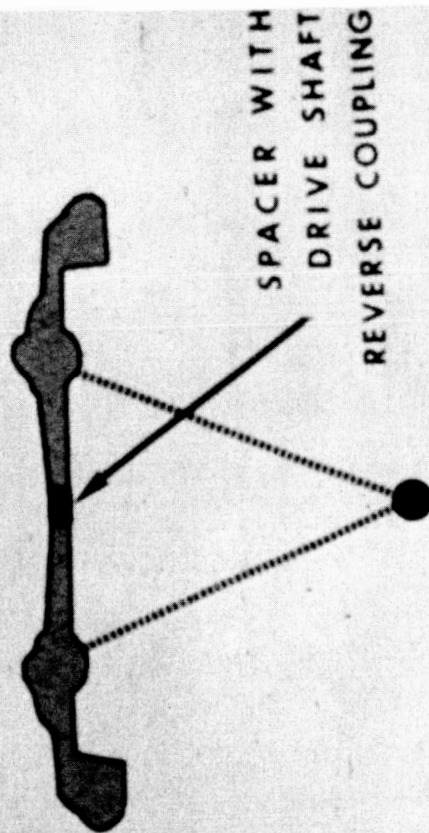
**FLEXIBLE
COAXIAL**



**SPREADER
BAR**



TWO POINT PENDANT



PSEUDO TANDEM

SPACER WITH
DRIVE SHAFT
REVERSE COUPLING

TRAIL

LEAD

HOIST CABLE

SPREADER BAR

LOAD CABLES

LOAD

65'

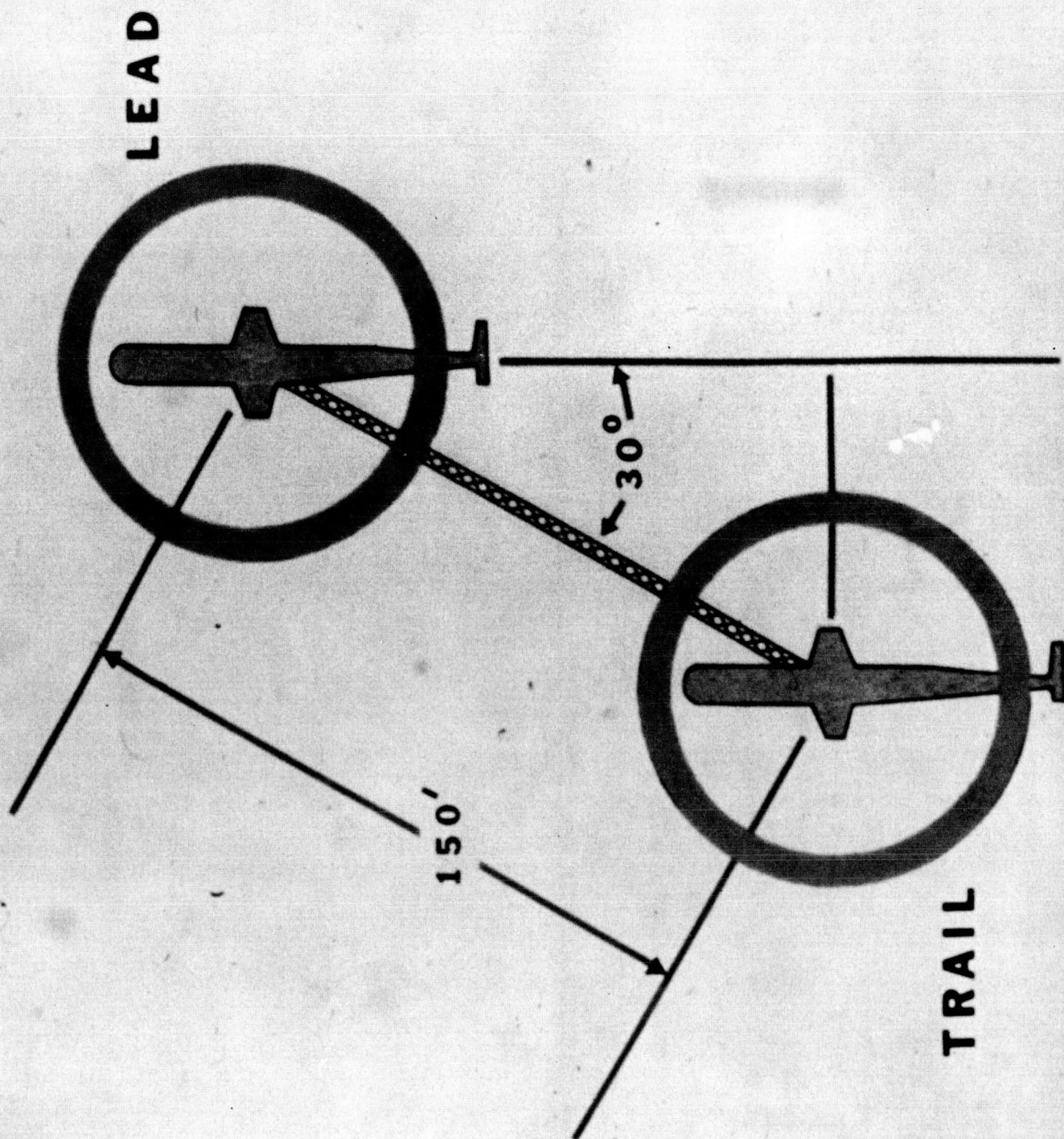
150'

150'
TYP

210'
APPROX

50'

FORMATION FLIGHT (TOP)





SIKORSKY CH-54B TWIN LIFT SYSTEM

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**TWIN-LIFT SYSTEM SPREADER BAR:
HOOK ATTACHMENT, STRIKER ARM AND CABLING**

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VI-176

SIKORSKY/ARMY FEASIBILITY DEMONSTRATION

CONCLUSIONS:

- . CONCEPT APPEARS OPERATIONALLY FEASIBLE
- . OPTIMUM FORMATION CONFIRMED
- . SYSTEM MORE STABLE THAN PREDICTED
- . 20-TON LIFT BY CH-54 TO 20 KNOTS IS FEASIBLE
WITH STANDARD AFCS
- . TO EXPAND FORWARD FLIGHT ENVELOPE WILL REQUIRE
AUTOMATIC CONTROL TO REDUCE PILOT WORKLOAD

MASTER SLAVE CONCEPT

. MASTER HELICOPTER PILOT FLIES LOAD

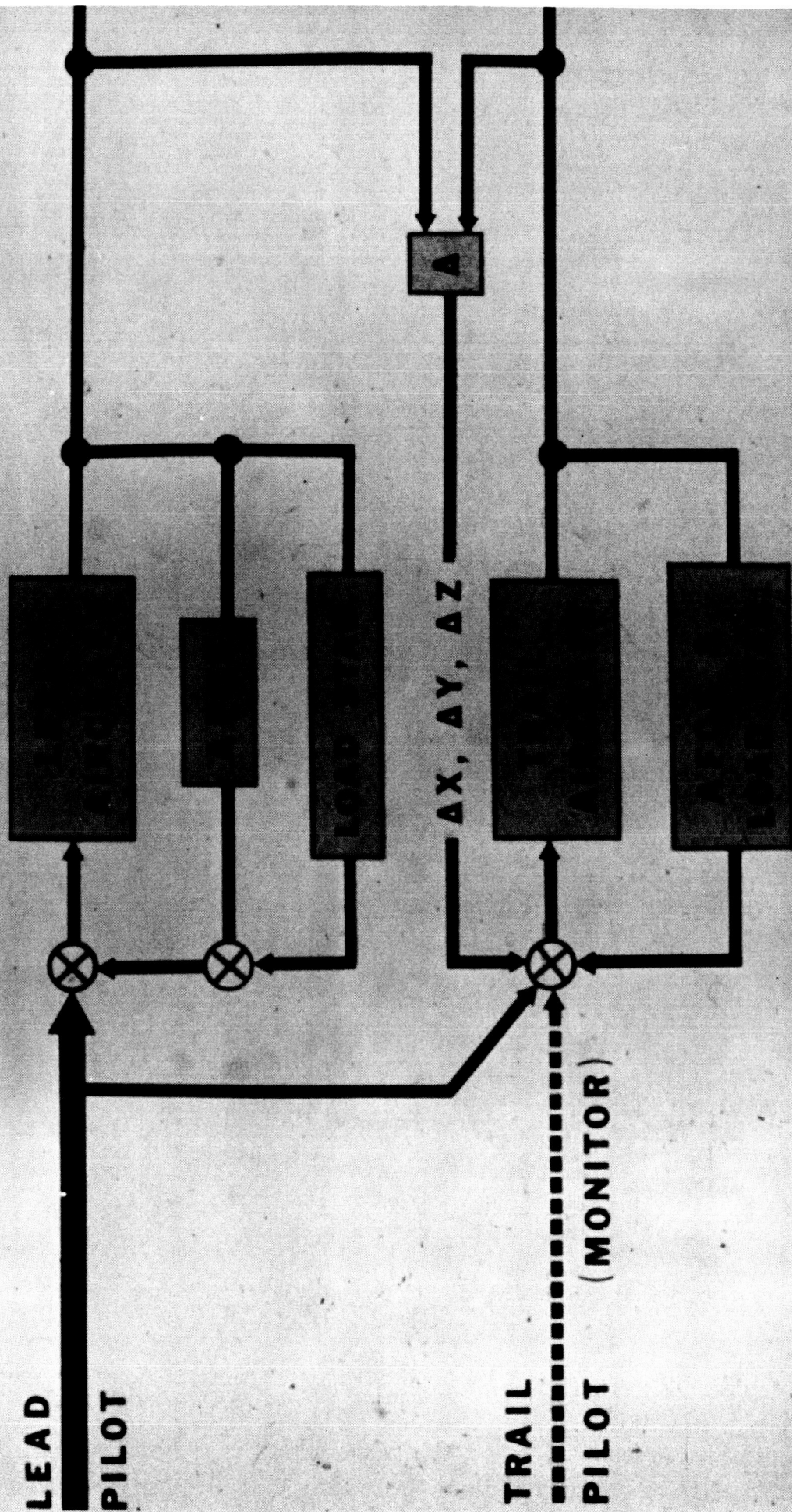
. SLAVE MAINTAINS:

. SEPARATION

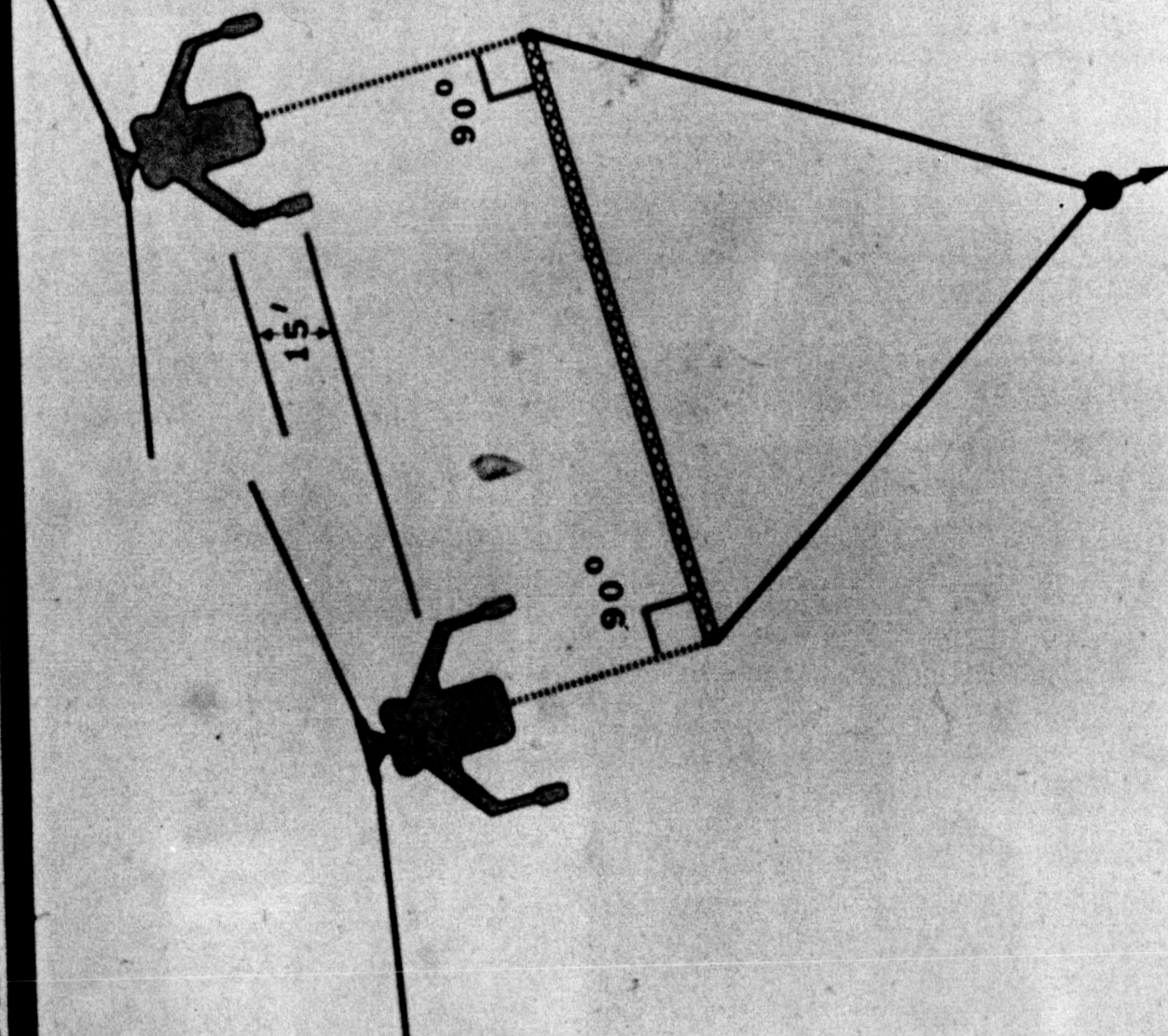
. SPREADER BAR LEVEL

. SPREADER BAR AZIMUTH

"MASTER-SLAVE" CONCEPT



AIRCRAFT POSITION IS MAINTAINED IN A TURN

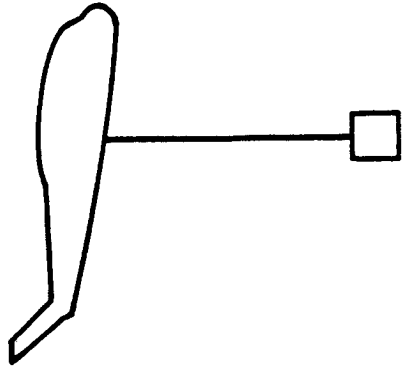


R&D NEEDS

- . DEMONSTRATE MASTER SLAVE CONTROL
- . DEVELOP LIGHT WEIGHT COLLAPSIBLE SPREADER BAR
- . SUPPORT OPERATIONAL DEMONSTRATION

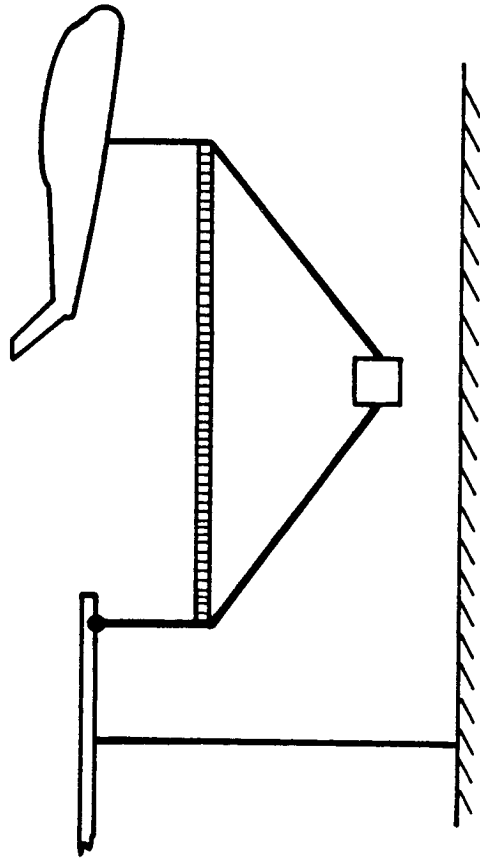
MASTER SLAVE BUILD UP DEMO

1. SIMULATION
 - LRC CH-54 SIMULATION REACTIVATED AT AMES
 - SELECT CONTROL LAWS
 - GROUND TEST SLAVE CONTROL SYSTEM HARDWARE
2. SLAVE HELO SINGLE LOAD TEST
 - CONFIRM LOAD STABILIZATION GAINS & STABILITY

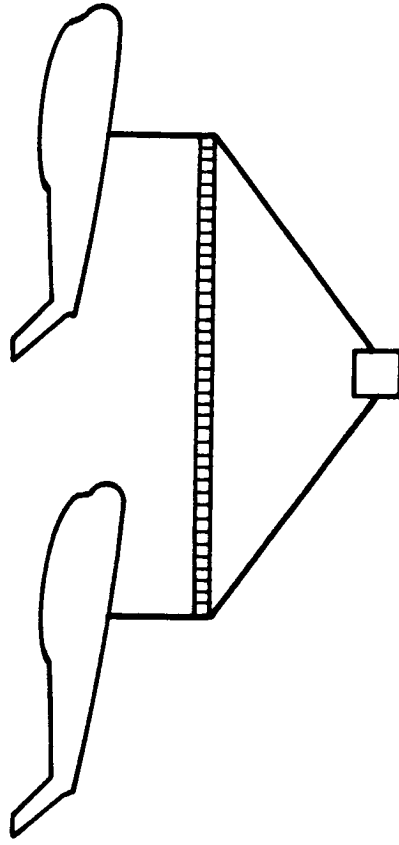


MASTER SLAVE BUILD UP DEMO - CONT'D

3. SINGLE HELO - SPREADER BAR



4. TWIN LIFT FULL MASTER - SLAVE

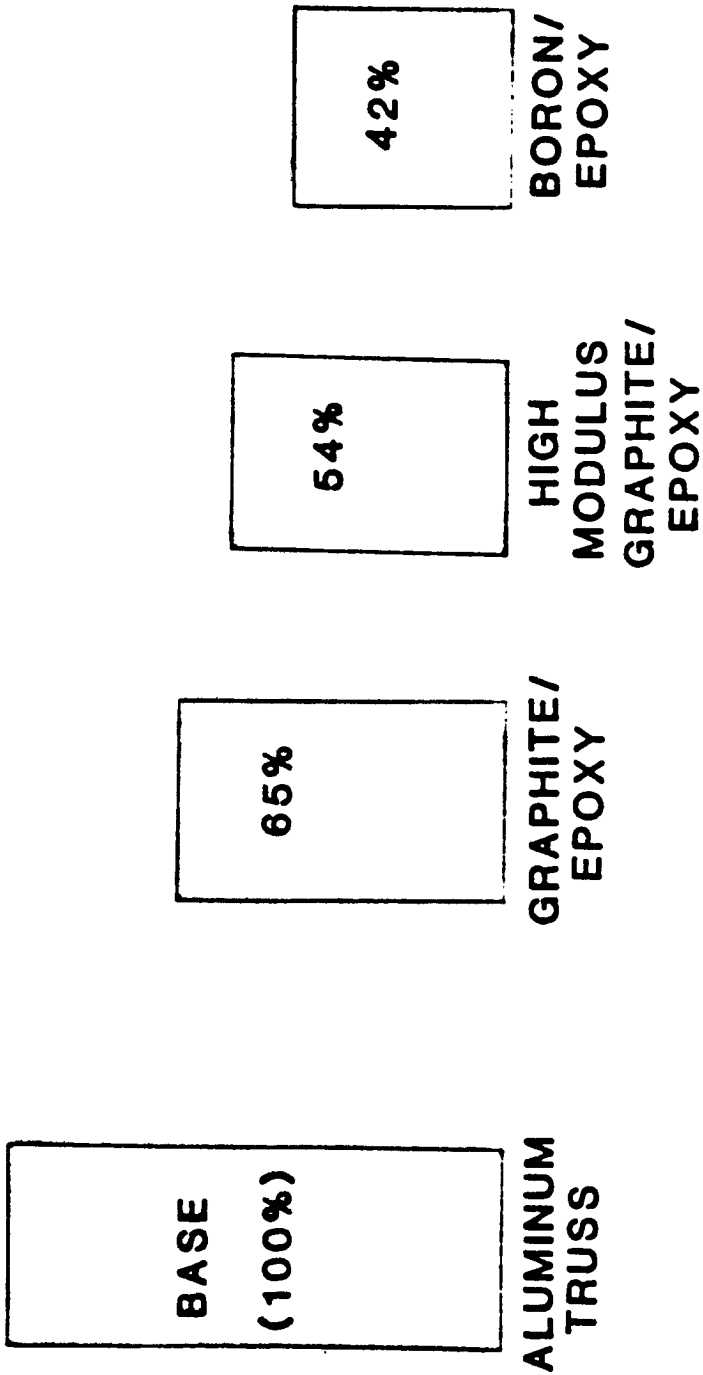


TWIN LIFT BOOM - R & D REQUIRED FOR COMPOSITE DESIGN

- PRELIMINARY DESIGN ANALYSIS
 - CONCEPTS
 - JOINTS & DISASSEMBLY
 - FABRICATION METHODS
 - MATERIALS
- STRUCTURAL OPTIMIZATION
 - GEOMETRIC
 - MATERIALS
- FINAL DESIGN
 - INTEGRATE OPTIMIZATION
WITH FABRICATION

TWIN LIFT BOOM - PROJECTED WEIGHT REDUCTIONS WITH COMPOSITE MATERIALS

- LIGHTER WEIGHT
- EASIER HANDLING/TRANSPORT



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Hughes Helicopters

LARGE HELICOPTERS

By

Robert E. Head

The helicopter industry (manufacturers and users) has been interested in large helicopters almost from its beginning. For instance, less than ten years after Sikorsky flew the VS-300, the XH-17 was conceived and was flown a few years later. This helicopter had a 130 foot diameter rotor which is still the largest one ever flown.

Two paths were open to the designers of large helicopters --- shaft drive and tip jet drive. By far the greatest share of research and development has gone into shaft drive technology, and this is the only type of helicopter flying today. Shaft drive helicopters have reached the point in the CH-53E and XCH-62 where transmission systems are becoming a limiting factor because of the size, weight, cost, and manufacturing technology.

Jet drive helicopters have encountered problems with suitable engines, materials, and fuel consumption, and a fundamental law of physics that keeps their propulsive efficiency relatively low. Modern low bypass ratio turbine engines and structural and insulating materials make the jet rotor attractive, but the thermal efficiency problem must be circumvented.

Studies have shown that there is a cross-over point at a gross weight of approximately 100,000 pounds, below which the shaft drive is definitely the winner, but above which the jet drive is increasingly more attractive. Above this weight, the weight of the shaft drive transmission, the weight of the airframe and rotor to support it, and the fuel required to fly the helicopter are increasingly greater than the helicopter weight and fuel required by the jet helicopter. For example, a recent study of a heavy lift helicopter designed to transport the 60-ton main battle tank 100 nautical miles showed the following comparison of size and weight.

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Hughes Helicopters

	<u>Shaft Drive</u>	<u>Jet Drive</u>
Rotor Diameter, feet	230	185
Gross Weight, pounds	410,000	268,000
Empty Weight, pounds	194,000	91,000
Fuel Weight, pounds	93,000	54,000

Because shaft drive technology is so well advanced, it should now be the turn of the jet drive system. To the limited research that has shown the feasibility of the jet rotor, should be added new research based on modern technology to begin to bring it along to match the shaft drive helicopter.

The following steps are proposed for advancing jet rotor technology to a point where it can be considered ready for commercial applications:

- o Jet rotor design for RSRA
- o Multiple-engine operational study
- o Aero/thermo/structural test of insulated blade segment
- o Fabricate engine/jet rotor unit for wind tunnel test
- o Conduct wind tunnel test
- o Adapt wind tunnel components to RSRA for flight test

This work could then lead to large jet powered helicopters that could provide such useful commercial services as:

- o Construction
- o Logging
- o Oil Rig Support
- o Ship-to-Shore Cargo Transfer
- o Towing
- o Out-size Cargo Transport



LARGE HELICOPTER CONCERNS

SHAFT DRIVE

TIP DRIVE

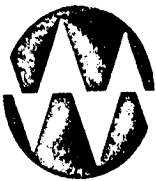
POWER TRANSMISSION

MULTI-ENGINES/COMMON PLENUM

TURBOSHAFT ENGINES

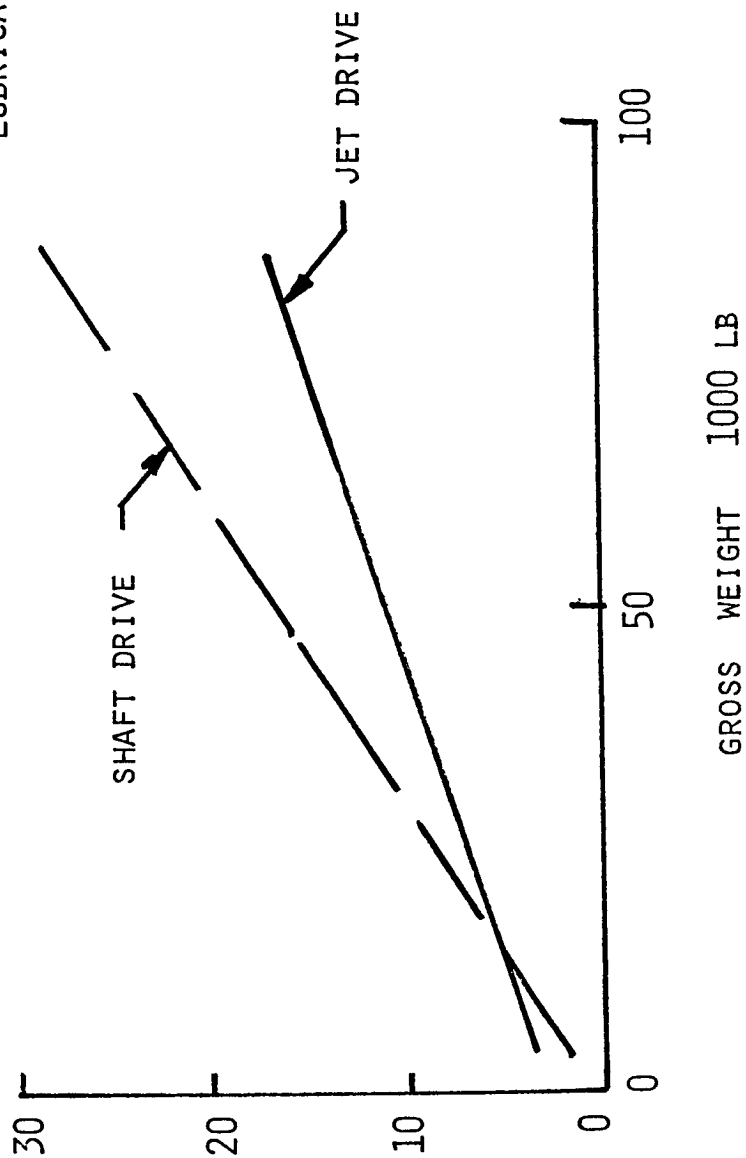
INSULATED BLADES

STATIC BLADE DROOP



LIFT - PROPULSION SYSTEM WEIGHT

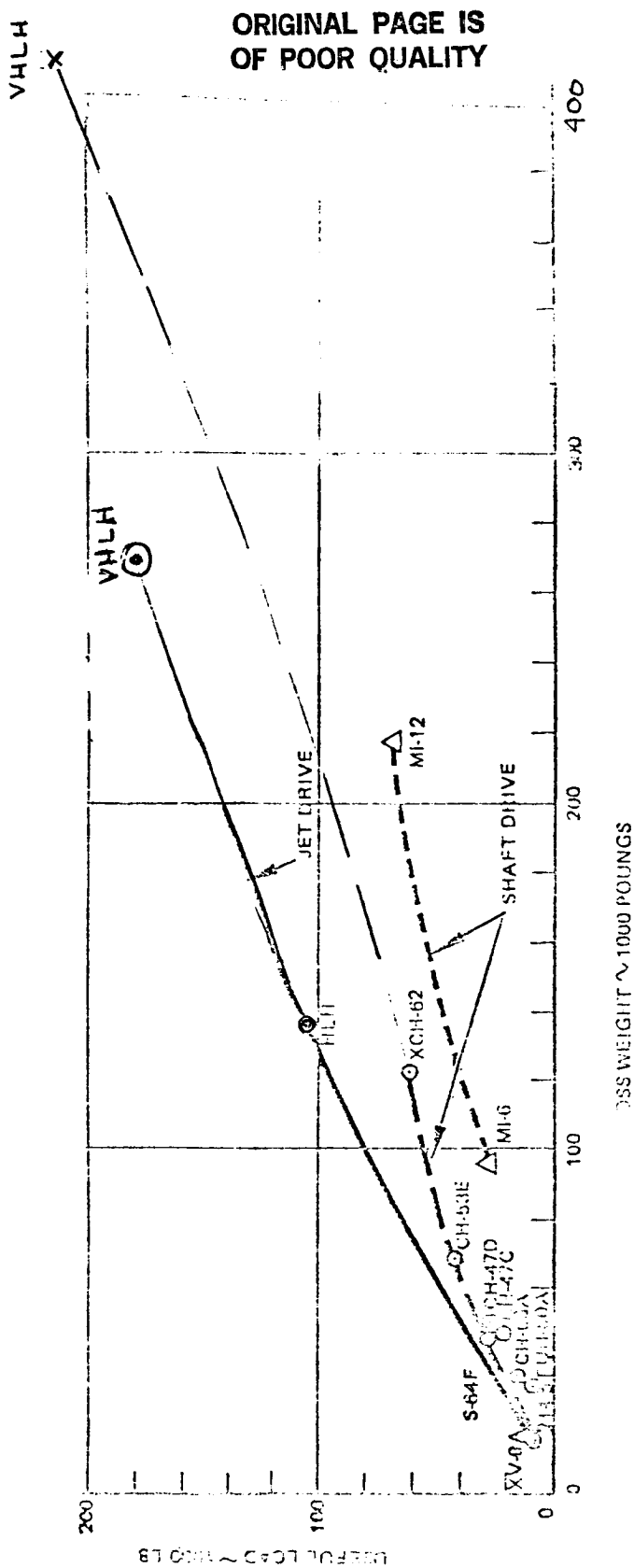
INCLUDES: LIFTING ROTOR(S)
DIRECTIONAL CONTROL
DRIVE SYSTEM
ENGINE(S)
LUBRICATOR



LIFT/PROPULSION
SYSTEM WEIGHT
1000 LB



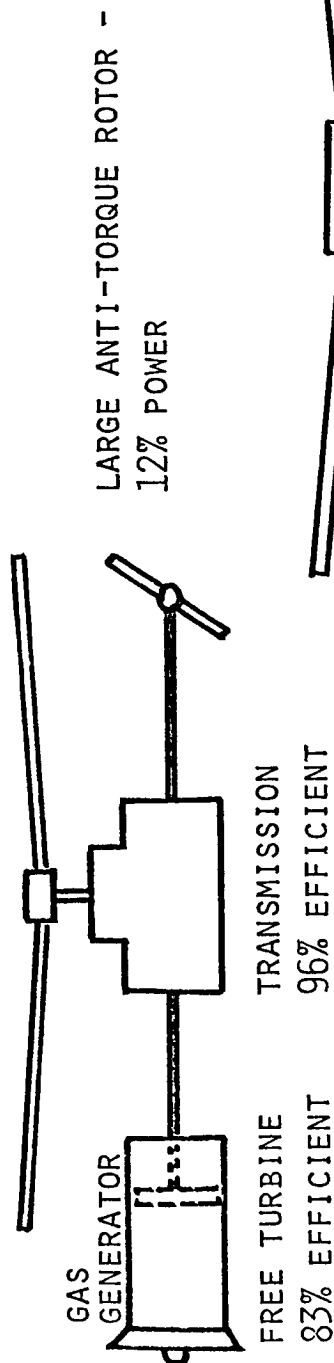
USEFUL LOAD/GROSS WEIGHT



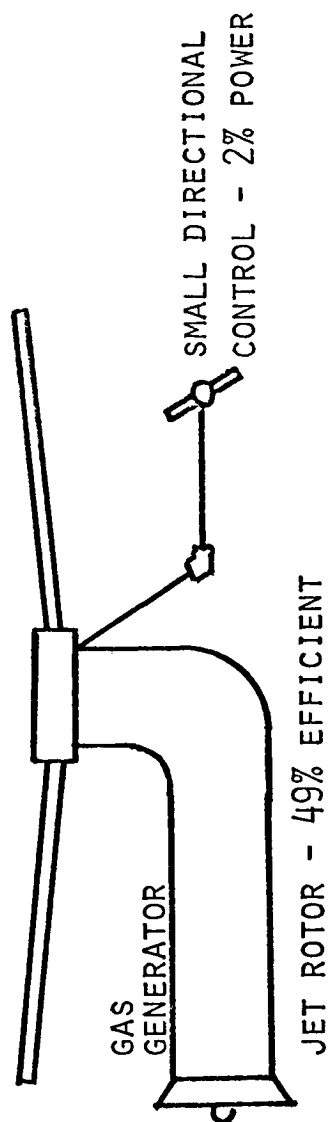


PROPULSIVE EFFICIENCY

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SHAFT DRIVE



JET DRIVE



HEAVY LIFT HELICOPTER MISSIONS

o CONSTRUCTION

o LOGGING

o OIL RIG SUPPORT

o SHIP-TO-SHORE CARGO TRANSFER

o TOWING

o OUTSIZE CARGO LIFT



SUGGESTED JET ROTOR RESEARCH

- DESIGN JET ROTOR FOR RSRA
- STUDY MULTI-ENGINE OPERATION
- TEST INSULATED BLADE SEGMENT
- BUILD ENGINE/JET ROTOR UNIT FOR WIND TUNNEL TEST
- ADAPT WIND TUNNEL TEST UNIT FOR FLIGHT TEST ON RSRA

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LARGE MULTIROTOR ROTORCRAFT CONCEPTS

John J. Schneider
Boeing Vertol Company
Philadelphia, Pa.

There are three questions I'd like to address in these next few moments: First, why develop large rotorcraft technology; then, given that, why develop multirotor technology, and finally, what are the research requirements? Throughout the history of the helicopter and airplane, in addition to speed, the primary emphasis has been on ever-increasing size, since transportation economics benefit greatly from the increased payload ratio and longer ranges (Figure 1). The early pioneers of rotary wing flight foresaw the promise of the helicopter, and even though in their eyes progress was very slow, in retrospect, the helicopter followed a similar growth pattern to the fixed wing airplane albeit displaced in time by nearly forty years. The phasing of the invention/demonstration periods, followed by early piston engine production, then early turbine engine production, and finally, a maturing business having a much expanded growth rate, appears typical of both.

The worldwide offshore oil explorations and support of the production oil rigs have already sparked an explosive growth rate in the smaller passenger transport roles. Here again, the pattern similarity to fixed wing is apparent. Figure 2 compares the seating capacity growth trends of both fixed wing and helicopters. The natural evolution to larger and larger aircraft is evident. It is hoped the helicopter can now, with the development of higher speeds and higher capacity, begin to be used in its fundamental role - that of short and medium stage commercial air transport between city centers. Similar to fixed wing, favorable growth patterns will imply a need for helicopters of larger and larger capacity.

Helicopter size growth, as seen in Figure 3, has been primarily a record of achievements by single and tandem rotor helicopters (except for the very large Russian MIL-12 lateral twin). Early attempts to develop quantum jumps in helicopter size were exemplified by the simple expedient of multiplying the number of lifting rotors - and the tandem helicopter, as well as lateral twins, trirotors, and quadrotors appeared on the scene. Of course, the apparent simplicity of adding rotors was afflicted with structural and dynamic problems and only the tandem multirotor helicopter has survived as the major type operated in the world today. Other early significant efforts to develop large helicopters were concentrated in the area of tip-drive rotor systems in order to eliminate development of large geared drives. Although a major portion of available R&D money was devoted to those systems, solutions for major challenges were never within reach and these concepts fell by the wayside. In the meantime, tremendous progress in weight reduction, increased power capability, and

reliability of the geared drives for helicopters was made, resulting in a continuous growth in size and efficiency.

In addition to sheer size growth, passenger comfort features are a natural fallout from the increasing size. Figure 4 shows the passenger arrangements for the Boeing 234 Chinook in its standard 44 seat layout, the stretched 68 passenger variant and the Boeing 307 airliner derivative of the HLH. Typical spacious cabin arrangements are shown in Figure 5. Passenger appointments, overhead racks, lavatories, and galleys are of the familiar fixed wing quality and the larger HLH derivatives can match the dual-aisle, wide body airplane's appeal.

Of course, the real advantage of increasing size (as well as advancing technology) is the reduction in direct operating cost per passenger mile. Direct operating cost estimates of this family of aircraft are shown in Figure 6 compared to current smaller and older helicopters. These values are getting comparable to existing fixed wing aircraft on short-haul routes of 100 to 300 miles, and coupled with a potential for much-reduced terminal costs should lead to a healthy growth in helicopter passenger services. Although the helicopter normally uses more fuel per passenger mile than a high flying fixed wing airplane, Figure 7 shows that the reduced block time spent in terminal maneuvers, traffic delays, and alternate weather routing can make the larger helicopters equally fuel efficient in the short-haul routes.

Well, what are the available civil markets for large multirotor rotorcraft? Yesterday we heard about almost all the possibilities and I've summarized the primary ones here (Figure 8): commuters, air freight, offshore oil support, on-shore resources exploration and support, construction, logging, and the potentially critical container offloading are the future for our industry. These next few examples illustrate the need for large rotorcraft. British Airways Helicopters has inspired our confidence in the future of a cross-channel commuter service from downtown London to the business centers of Europe (Figure 9). The introduction of a helicopter cross-channel passenger service will prove attractive to the business travel segment requiring daily round-trip rapid transportation service between concentrated business centers such as the three routes shown in Figure 10. Probably the most attractive consideration for the passenger is the time savings available (in addition to the elimination of long, traffic-snarled journeys to the airport) as shown in Figure 11. For the business traveller, this can mean about three more hours available during business hours without the aggravation of very early-morning departures and late-night returns.

In the U.S.A., deregulation of the airlines could provide the spark and the business volume to allow a short-haul airline operation with Boeing 234's (Figure 12). Even before deregulation, the trend in airport congestion seemed to eventually force use of helicopters. Now, since deregulation, the rapidly growing commuter activity has had a severe impact on hub cities and airport capacity is being strained to the breaking point. Creation of supplemental short-haul helicopter operations from the smaller cities to the hub cities could relieve this congestion without restricting growth and in addition,

since probably only about thirty percent really want to go directly to the hub city airport, the downtown city-center traffic can be siphoned off to further reduce airport congestion and increase growth. Commuter passengers are showing that they value their time and are willing to pay enough to create this new capacity. As more and more passenger traffic is created, perhaps at the predicted growth rate of fifteen percent or more per year, larger and more economical helicopters can be phased in and fill the needs of an ever-increasing number of city pairs for fast short-haul service.

Inevitably, as it has in the fixed wing business, the air freight opportunities will be there for the enterprising entrepreneurs as seen in Figure 13. In addition to the need for crew transport, North Sea oil operators are eagerly awaiting the utility capability of the 234 Chinook for external loads, and the development of larger rotorcraft would further increase the capability for oil rig construction during rough sea conditions (Figure 14). In the construction and logging industries (Figure 15), the hook capability of large helicopters has proven highly desirable. Even though the recession has temporarily put a damper on these operations, future markets in both the U. S. and other parts of the world hold much promise. Since 1971, pioneering efforts by Columbia helicopters, Evergreen, and others in logging operations, have shown the value and competitiveness of helicopters in certain applications. The typical helicopter lift (shown in Figure 16), eliminates the need for additional costly road building as well as conforming to recent environmental restrictions, thus allowing harvesting of valuable timber which would otherwise be unavailable. The keys to economical airborne yarding of timber are acceleration and speed plus superior pilot skill in maneuvering for load pickup and drop off. "A difference of fifteen to twenty seconds in average turnaround time can often be the difference between profit or loss".

Seaports in most underdeveloped nations are unable to offload containerships. In one case, a few years ago, more than one hundred ships were awaiting berthing spaces. The large helicopter is here again a logical solution to that problem as seen in Figure 17.

Assuming that the preceding fairly portrays the need for large rotorcraft; now, what is the need for large multirotor rotorcraft? Well, there are as we all know, many ways to skin the cat (Figure 18). In the development of very large helicopters, the primary problems are those of ever-increasing transmission torque and larger rotor diameters which can result in state-of-the-art limitations on the payload and size of the helicopters.

Fortunately, the tandem rotor configuration, aside from its attractiveness in solving the anti-torque requirements, has been primarily effective in allowing much smaller rotor diameters as well as reduced disc loadings. Figure 19 reflects the general trend showing recent helicopter rotor diameters with respect to payload. Figure 20 defines the disc loading trends of these configurations and also projects the trend for very much larger aircraft. The extremely high disc loadings for the larger single rotor aircraft are necessary in order to control the blade coning angle! Obviously, as you increase the number of rotors, lower disc loadings and smaller diameters are possible within these and other transmission constraints. Over the past twenty-five or thirty years we have studied the poten-

tial of multirotors many times and, even though the smaller component sizes were very appealing, the increased structural complexities and weight, the seriously increased mechanical complexity resulting in low reliability and safety, and the increased costs have far outweighed their perceived advantages! In summary, we believe the tandem rotor configuration offers an efficient multirotor system capable of providing the necessary payload capabilities far into the 21st century! In order to define tandem helicopter growth potential, recent Boeing configuration studies and parametric analyses examined very large tandems and it was found that tandem helicopters exhibit the same efficiency advantages of size as do fixed wing airplanes and within the range of gross weights studied, there are no formidable reasons why the tandem helicopter cannot continue to grow in size. The next two figures summarize these parametric analyses.

As a result of the HLH ATC program, further evidence is available to establish this trend in useful load ratio resulting from advancing technology (Figure 21). Since this is primarily a trend of progressively larger helicopters, it does illustrate how advancing technology has allowed us to defeat the square/cube law similarly to fixed wing aircraft. Combining those characteristic trends for large tandem helicopters, along with mission fuel calculations, a continuous improvement with size is apparent for the critical parameter of payload fraction (Figure 22). The tandem follows the same trend as do fixed wing aircraft and, in general, the message is pretty clear: Large tandem helicopters provide a viable growth potential showing every efficiency advantage of size growth similar to fixed wing airplanes! For instance, it's not inconceivable that 500 passenger capacity tandem helicopters could be built to match the 500 passenger 747's.

What, then, are the tandem multirotor research requirements? Briefly, the present status (Figure 23) of large rotorcraft technology is a result of the major steps taken in the early seventies with the initiation of the U. S. Army's heavy lift helicopter advanced technology components program and the building of the research vehicle to provide the flight test proof of concept. Although the cancellation of the program by Congress came before final completion and flight tests, the assets are still available and the technologies, demonstrated during the ATC, provide the capability for future cost/effective advanced research programs. At the present time, the NASA transmission technology program is underway to further develop the design technology for large, high power, lightweight spiral bevel gears using ATC components.

Just to refresh your mind on what was demonstrated and what hardware is available for further research, Figure 24 illustrates the system integration areas demonstrated during the ATC: Rotor whirl tests of advanced fail-safe fiberglass rotors with titanium hub and nonlubricated bearings; triply redundant fly-by-wire flight controls with digital AFCS demonstrated linear velocity control and a hover hold system in the 347 flight tests; and a pneumatic powered fail-safe 35 ton cargo hoist system. Integration of the aft rotor, drive, and engines were tested in the test rig shown in the figure. And, of course, the partially completed airframe (Figure 25) is being

stored. The fuselage was the first to use large honeycomb composite panels for all primary structure. Figure 26 shows the aft rotor transmission which will be used in the on-going transmission technology program. Static strain surveys and development of a finite element method for gear stress prediction, along with our spiral bevel gear stress data base will be correlated with the 50-hour test of the aft transmission.

Figure 27 describes our recommendations for large rotorcraft R&D. First, since the present transmission program underway is only 50-hours, it is essential that extended transmission qualification be undertaken. The assets are available to provide low-cost state-of-the-art data for full confidence. Following the extended transmission testing, the fabrication of components and the flight research vehicle is essential and should be completed. After completion of the flight substantiation program, which I'll discuss further in a moment, the research vehicle would then be available for further large rotorcraft research programs.

I think everyone knows that it's not enough to do only component testing. We must explore all the system integration problems associated with large rotorcraft and this can only be done by conducting full-scale flight testing (See figure 28):

- O Flight test would provide the systems integration and proof of concept for the technology development of the primary large rotorcraft components, and it would provide the data for evaluation of the honeycomb panel primary structure.
- O Flight test would provide assessment of the low frequency vibration environment peculiar to very large rotorcraft, and, as well, would provide the operational evaluation data so necessary to the mission suitability characteristics of very large rotorcraft.
- O With respect to suggestions of our operator's panel, the large rotorcraft research vehicle has the capability to place the loadmaster cab aft along the fuselage since controls are FBW and a long landing gear provides clearance. Also, since the aircraft has three engines and was designed to hover OGE with one engine out, these areas can be easily researched.
- O And, finally, flight test would provide a wealth of data and criteria for much larger payload size rotorcraft.

In conclusion, the HLH flight vehicle is representative of the size, the payload, and the technology of large cargo/transport helicopters that can be defined for civil and military applications in the 1990's. It provides a unique and timely opportunity for demonstrating a significant growth in helicopter lift capability. Completion and flight test of this vehicle offers the lowest cost, near-term alternative to establish the technology and explore the operational characteristics of large cargo/transport helicopters. The flight research program can; provide a technology data base for future programs, lower the risk of future large helicopter development, evaluate mission suitability, and reestablish U.S. preeminence in helicopter vertical lift capability.

HISTORICAL DEVELOPMENT

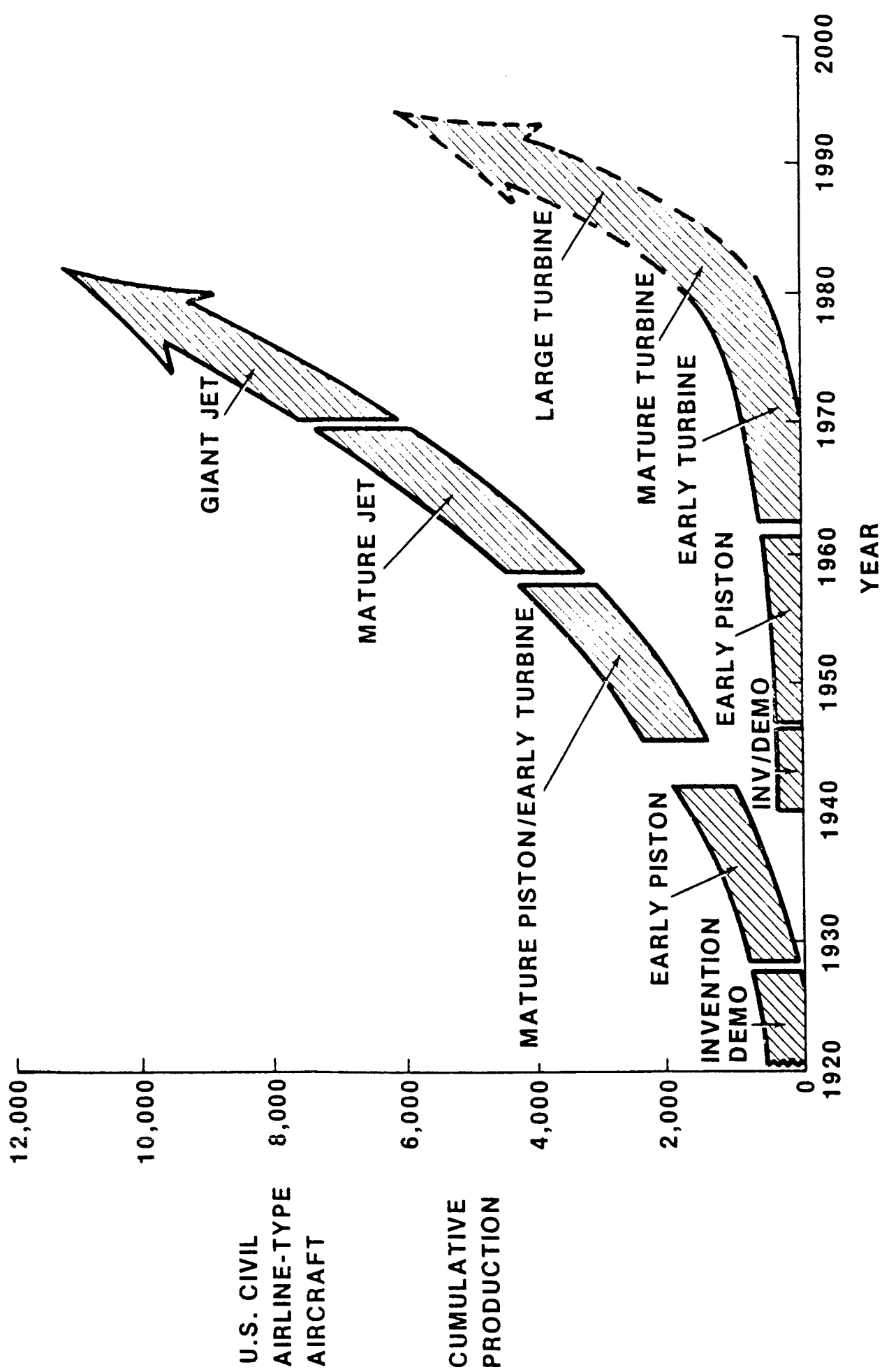
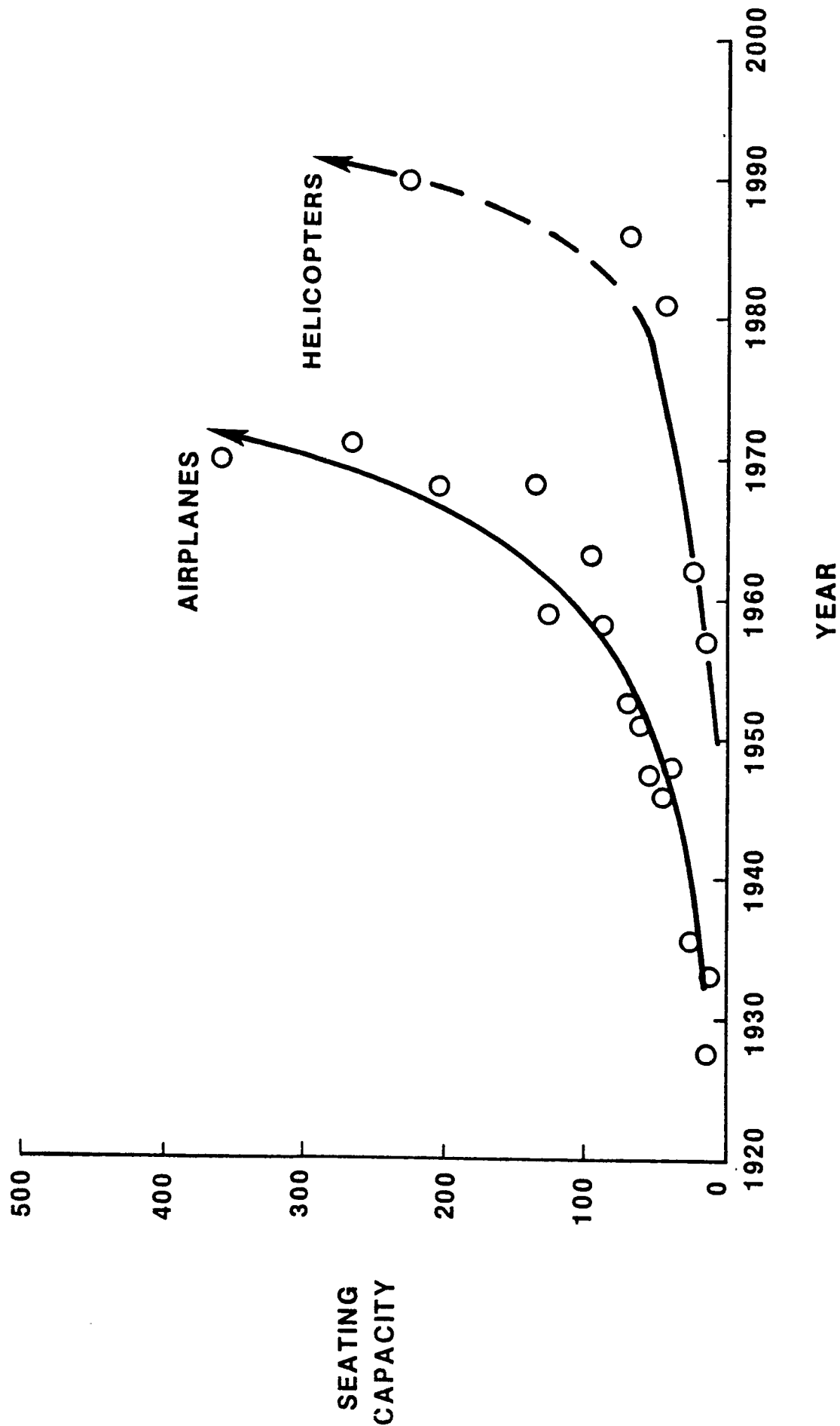


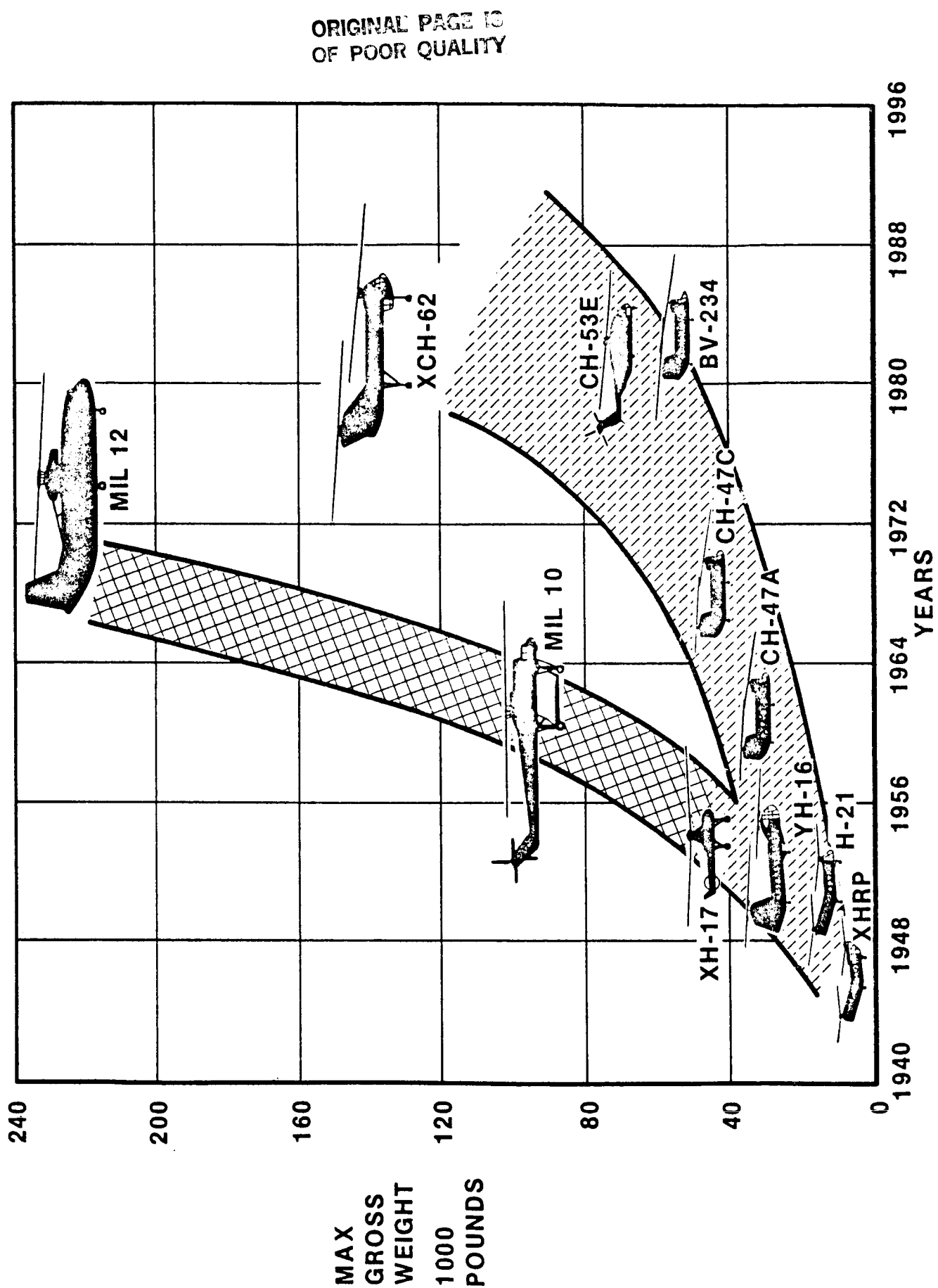
FIGURE 2

BOEING VERTOL COMPANY
A DIVISION OF THE BOEING COMPANY

SEATING CAPACITY GROWTH TREND

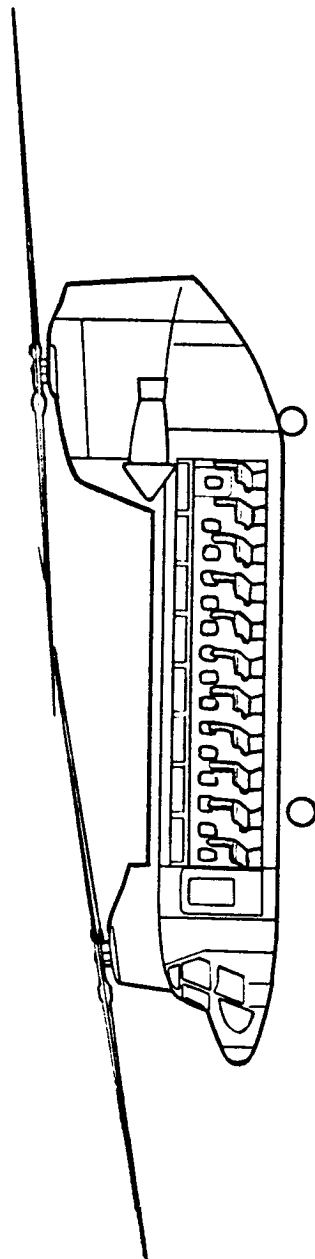


HELICOPTER GROWTH TRENDS

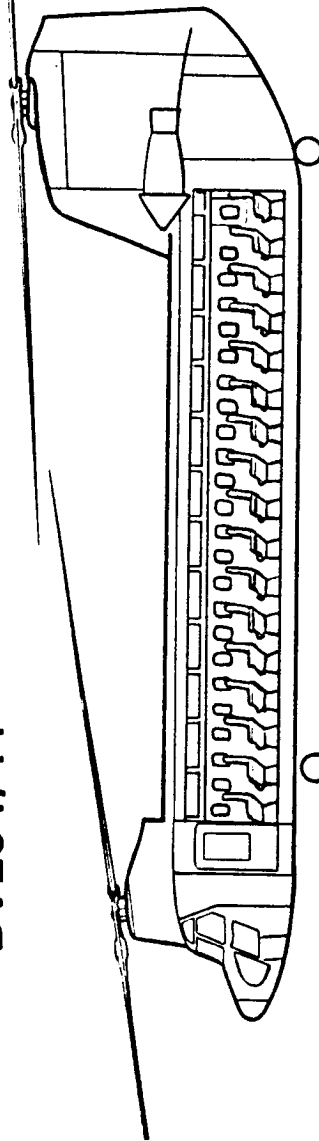


CABIN ARRANGEMENTS

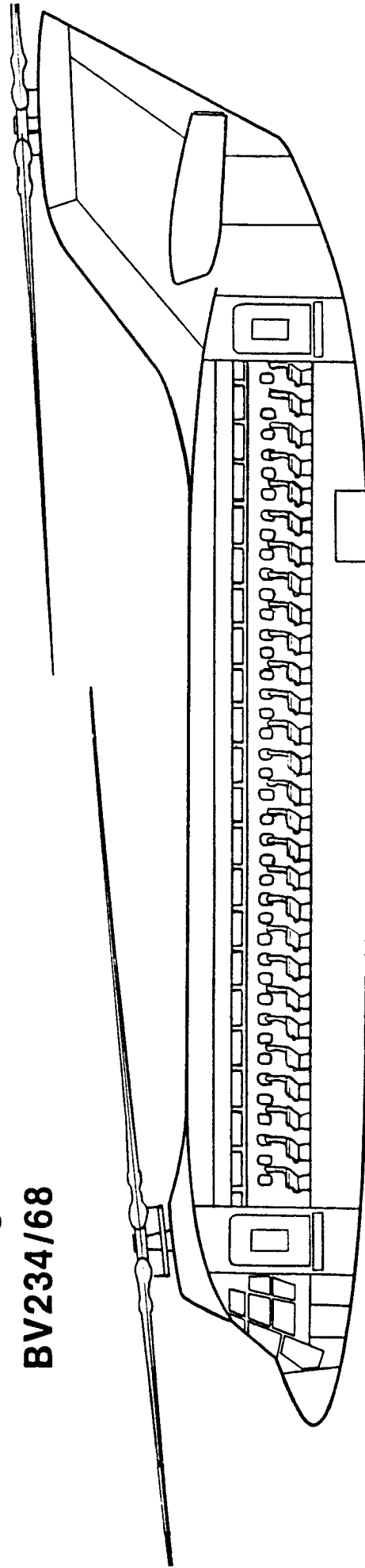
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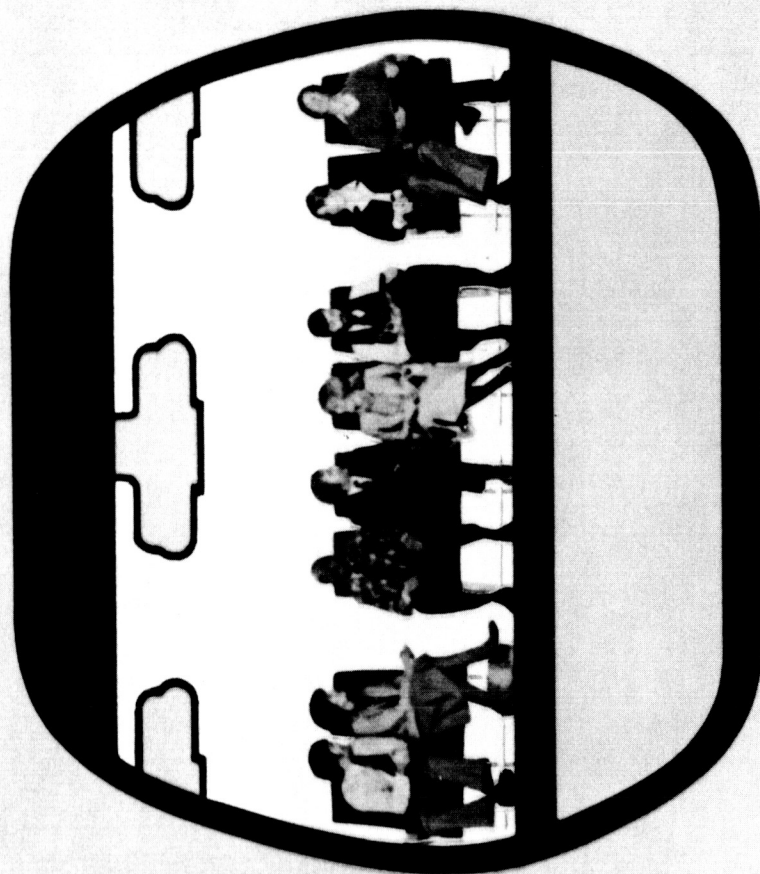
BV307/225

CABIN ARRANGEMENTS

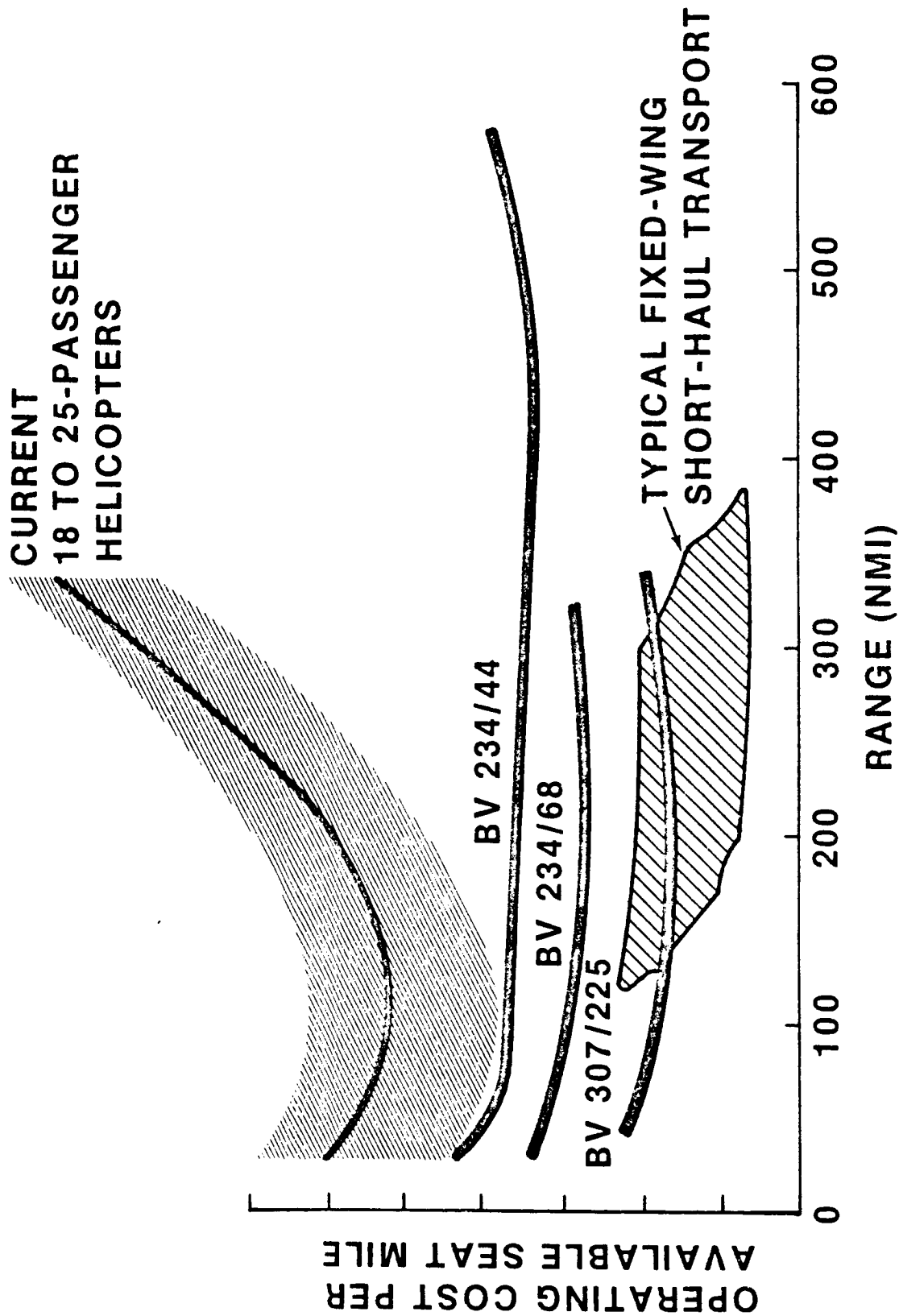
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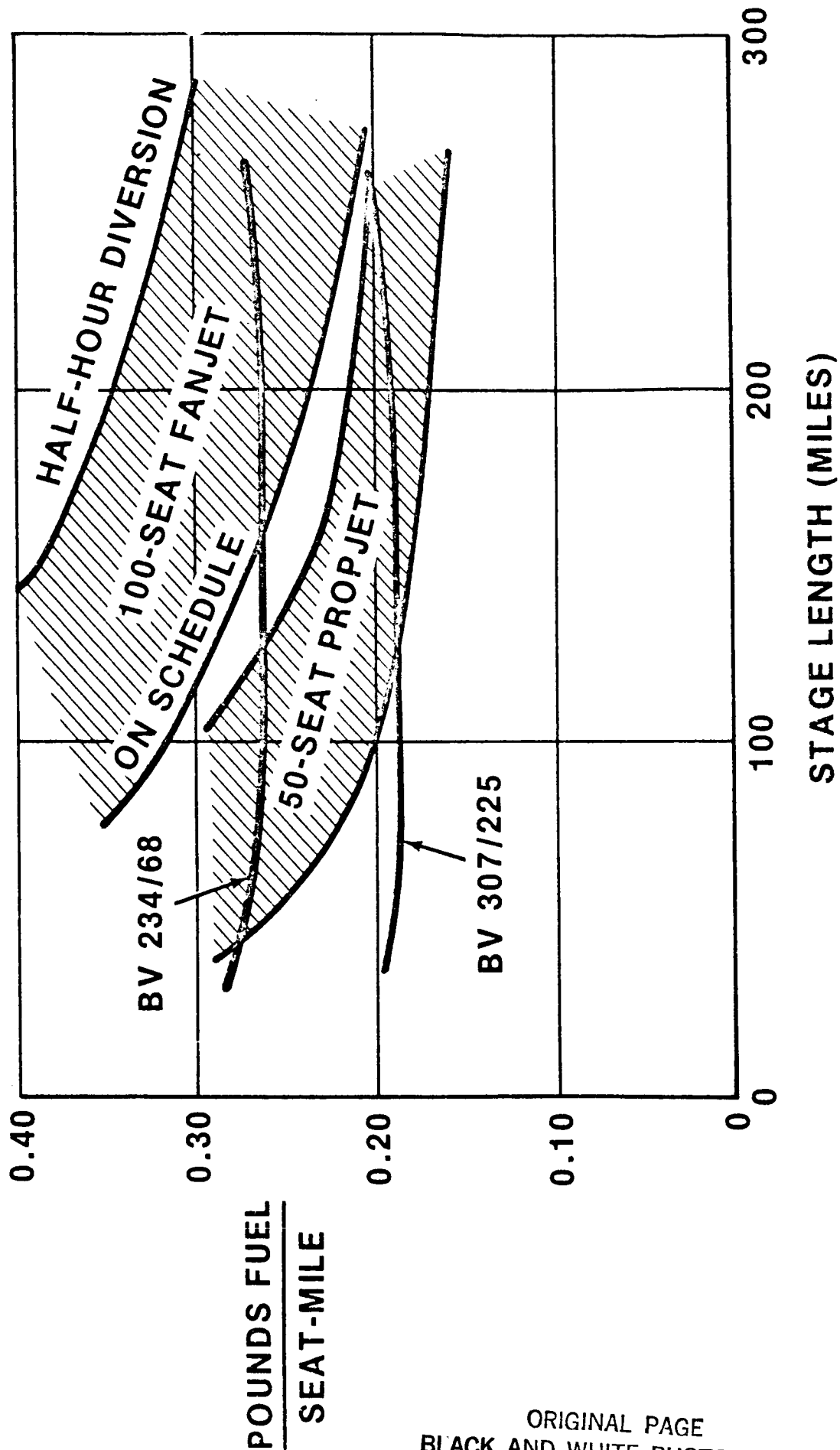
BV-307



COMPARATIVE DIRECT OPERATING COST



FUEL USAGE COMPARISON



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CIVIL MARKETS FOR
LARGE MULTIROTOR ROTORCRAFT

COMMUTERS

CONSTRUCTION

AIR FREIGHT

LOGGING

OFFSHORE OIL

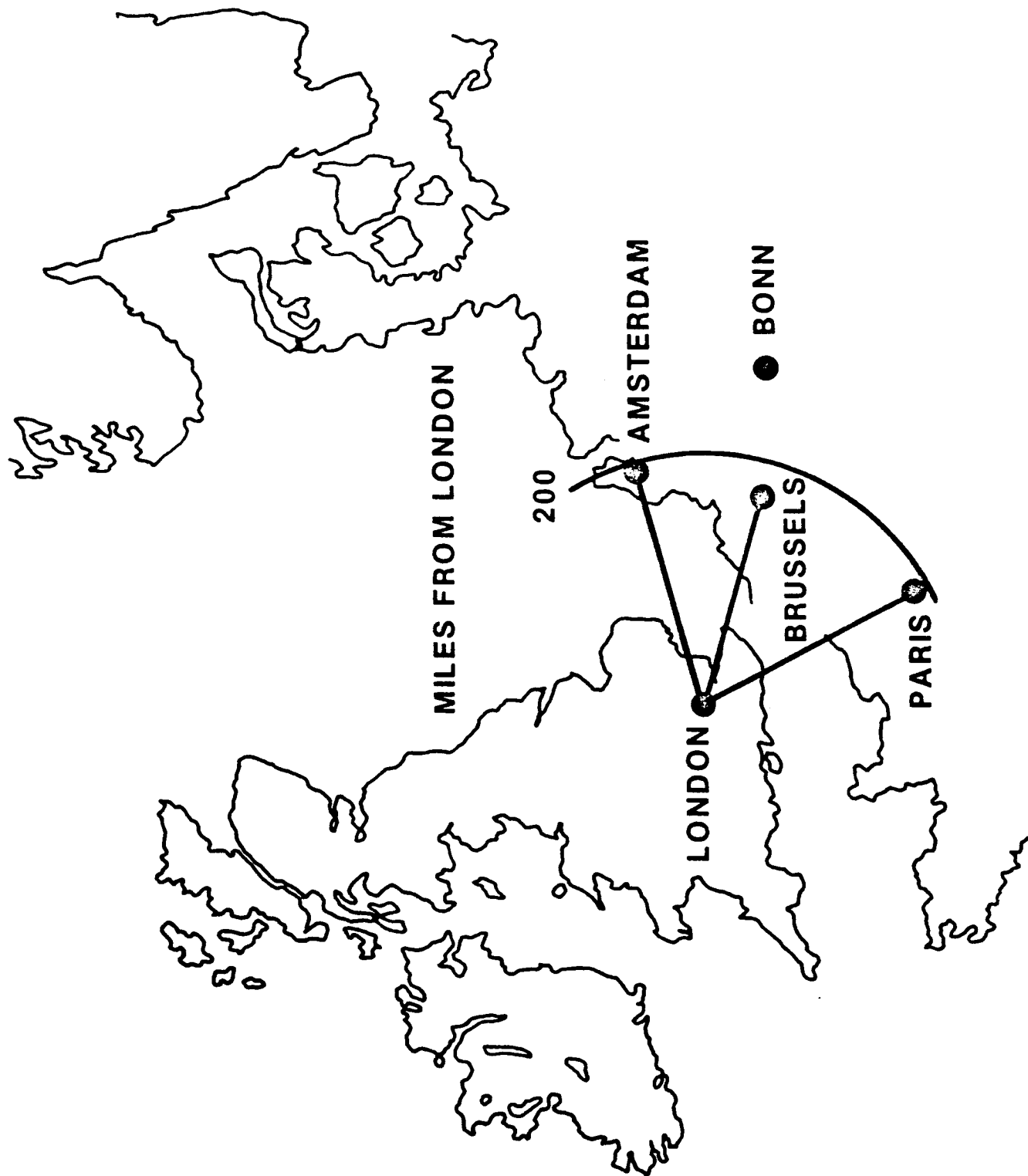
CONTAINERSHIP OFFLOADING

ON-SHORE RESOURCES



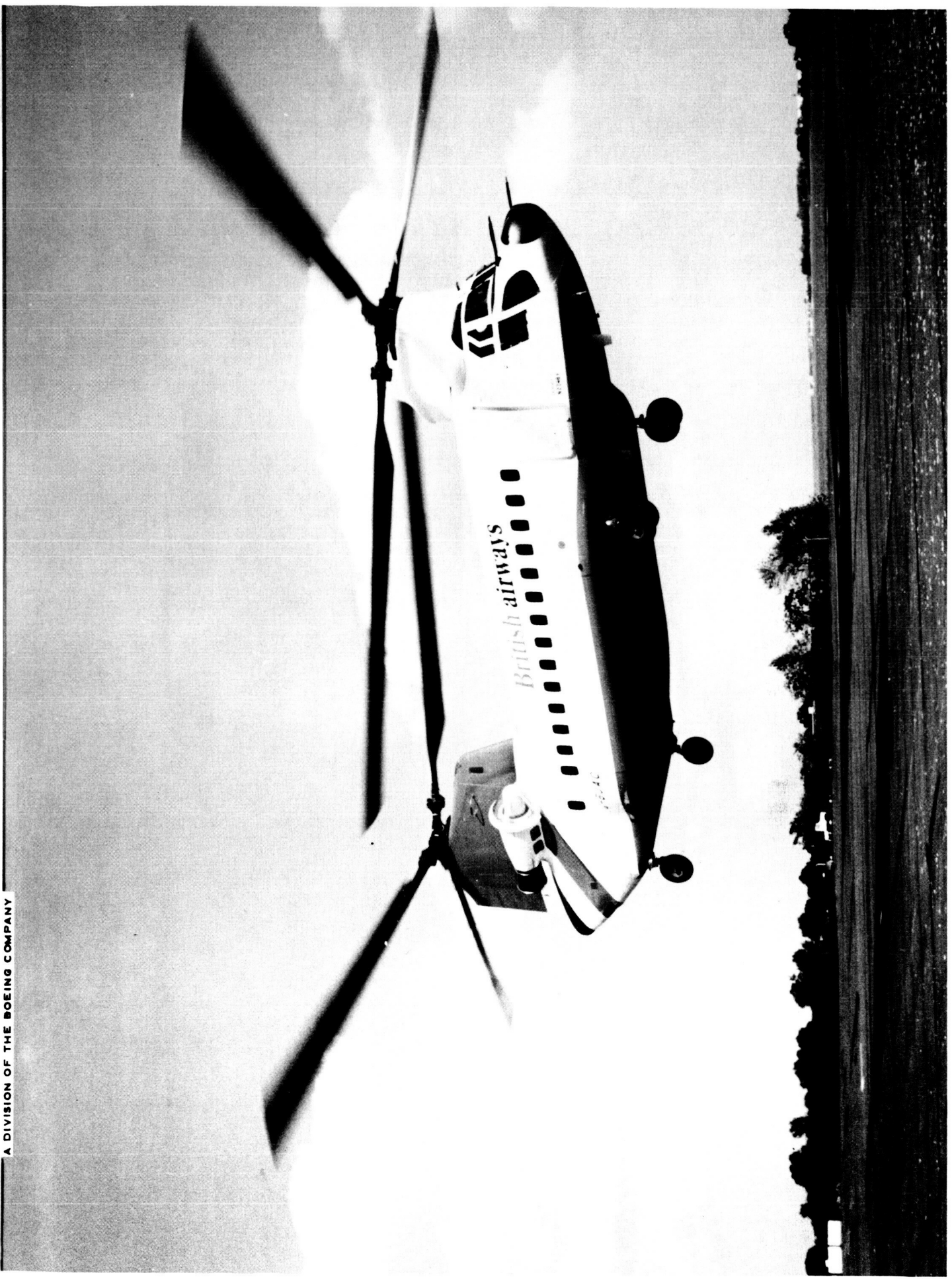
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CROSS-CHANNEL ROUTES



TIME SAVINGS — ROUND TRIP

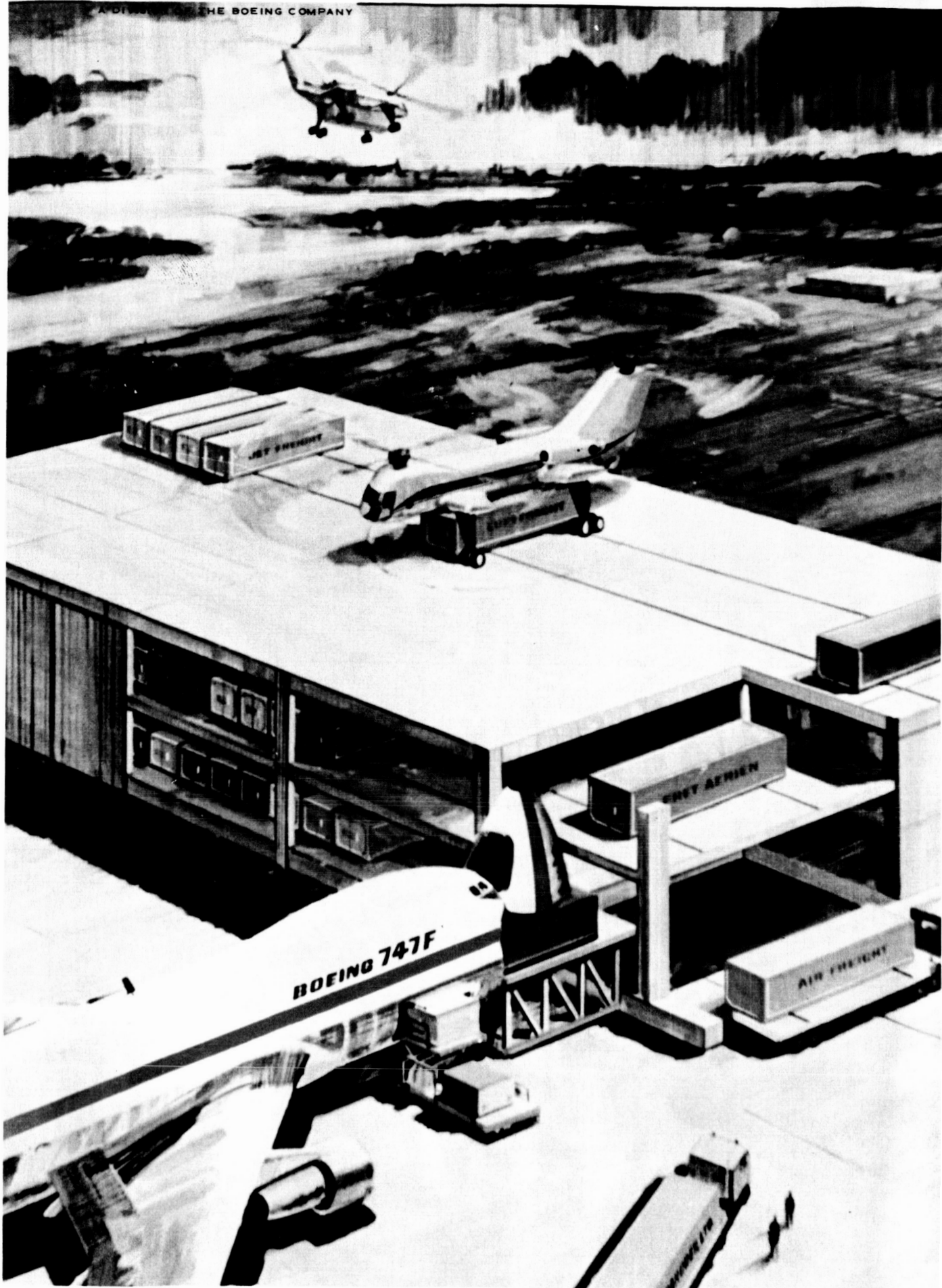
	TOTAL TRIP TIME (HOURS)		TIME SAVINGS HOURS
	FIXED WING	HELICOPTER	
LONDON — PARIS	9.25	5.75	3.50
LONDON — AMSTERDAM	8.95	5.80	3.15
LONDON — BRUSSELS	8.55	5.45	3.10

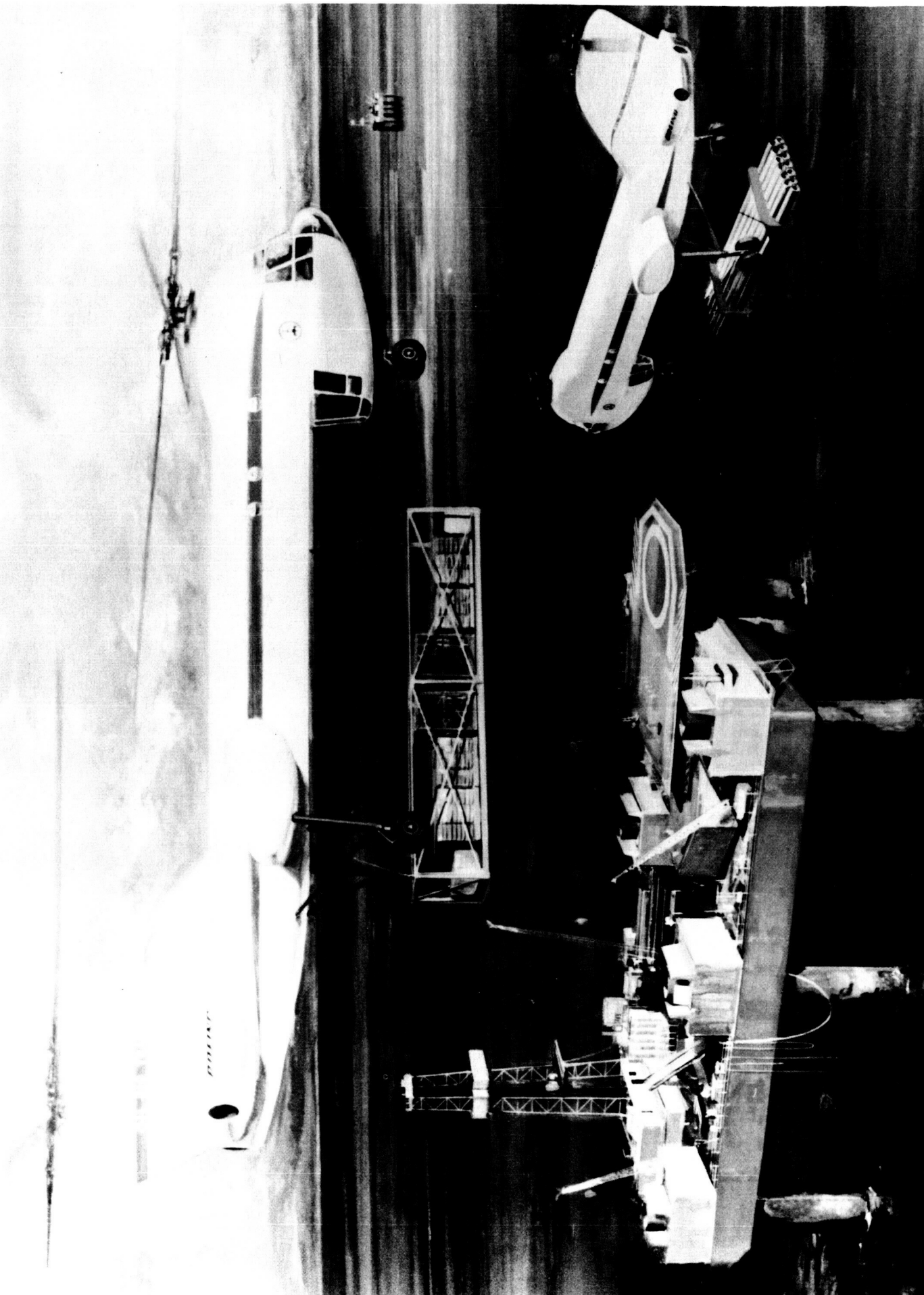


VI-211

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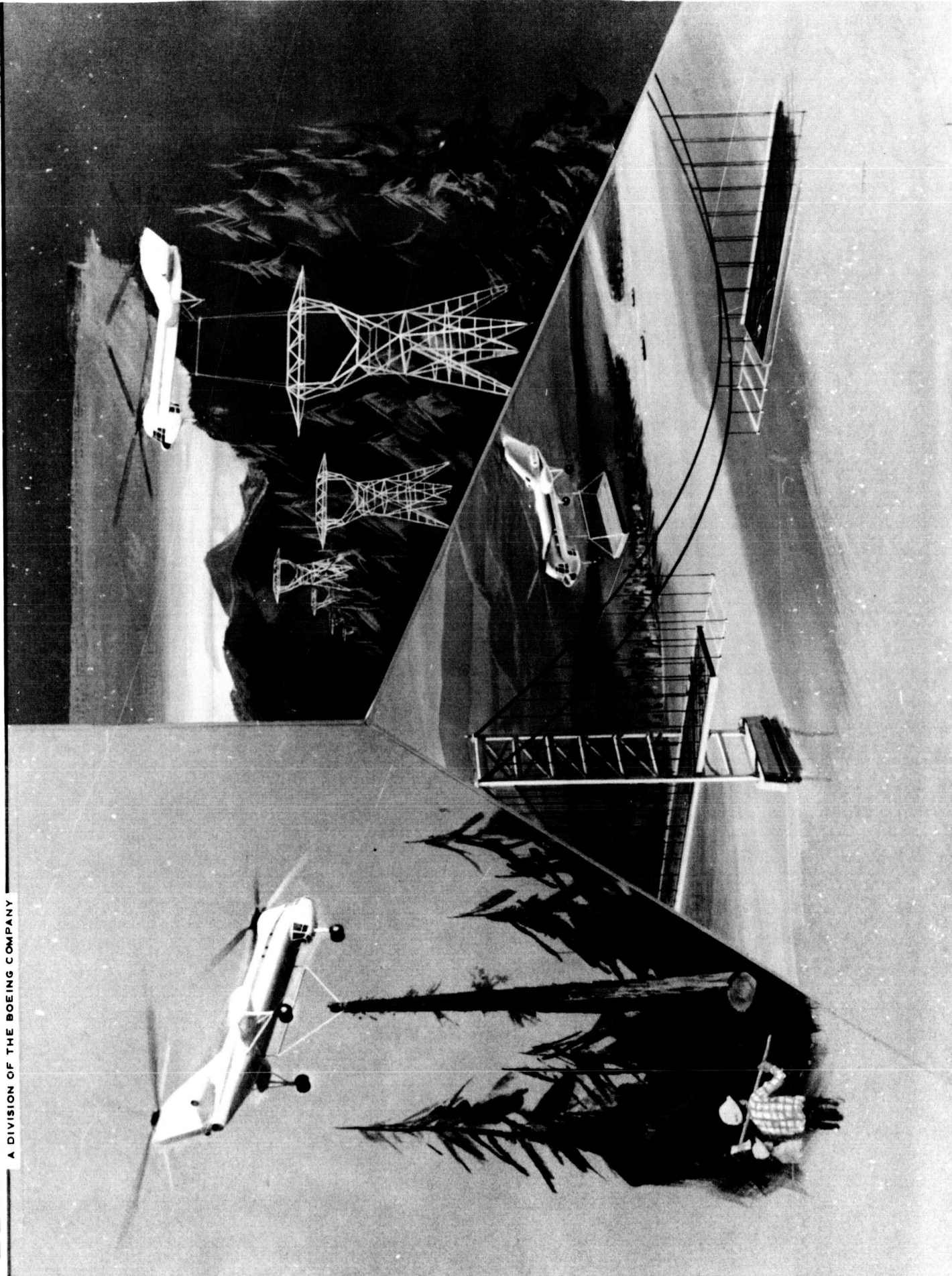
A DIVISION OF THE BOEING COMPANY



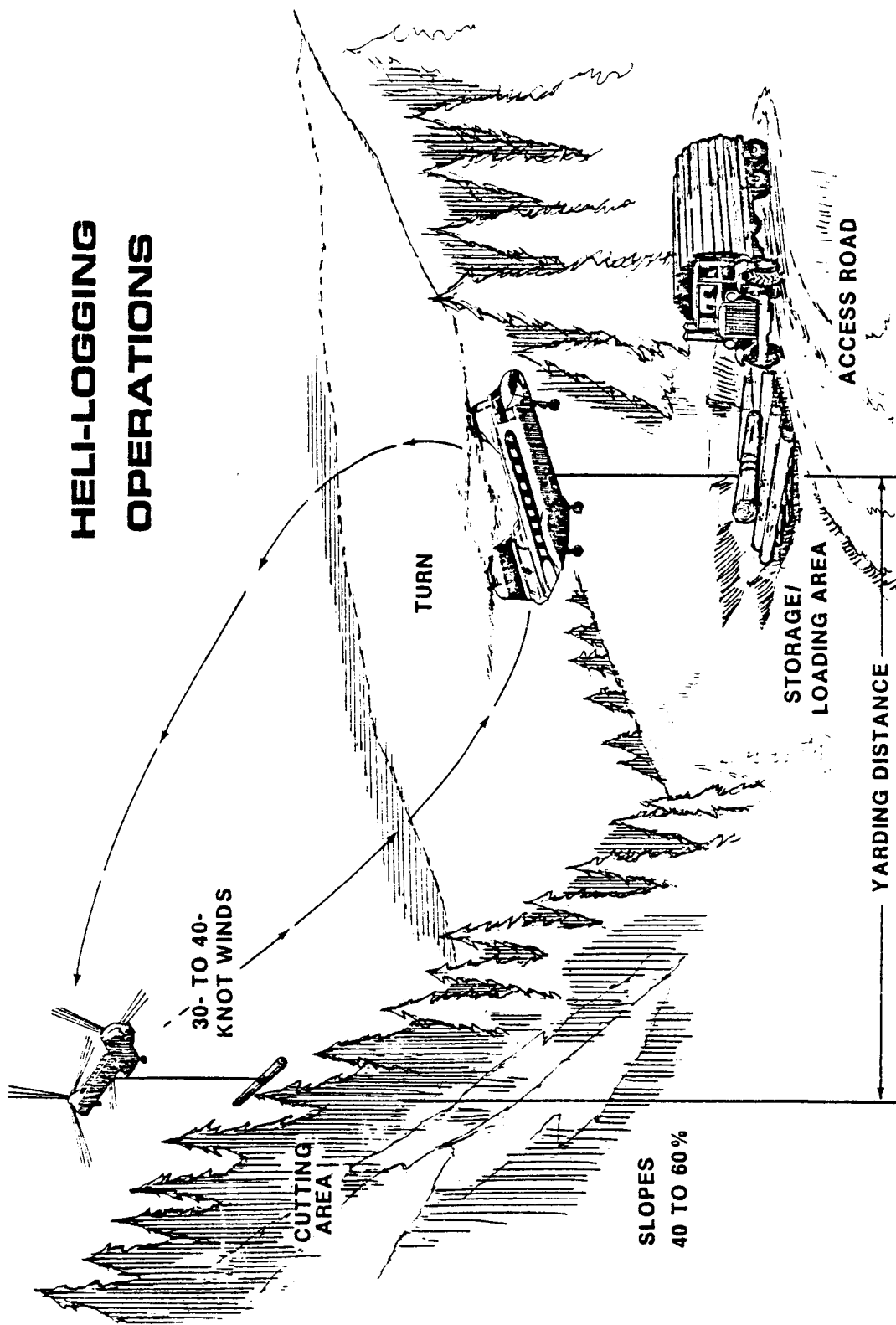


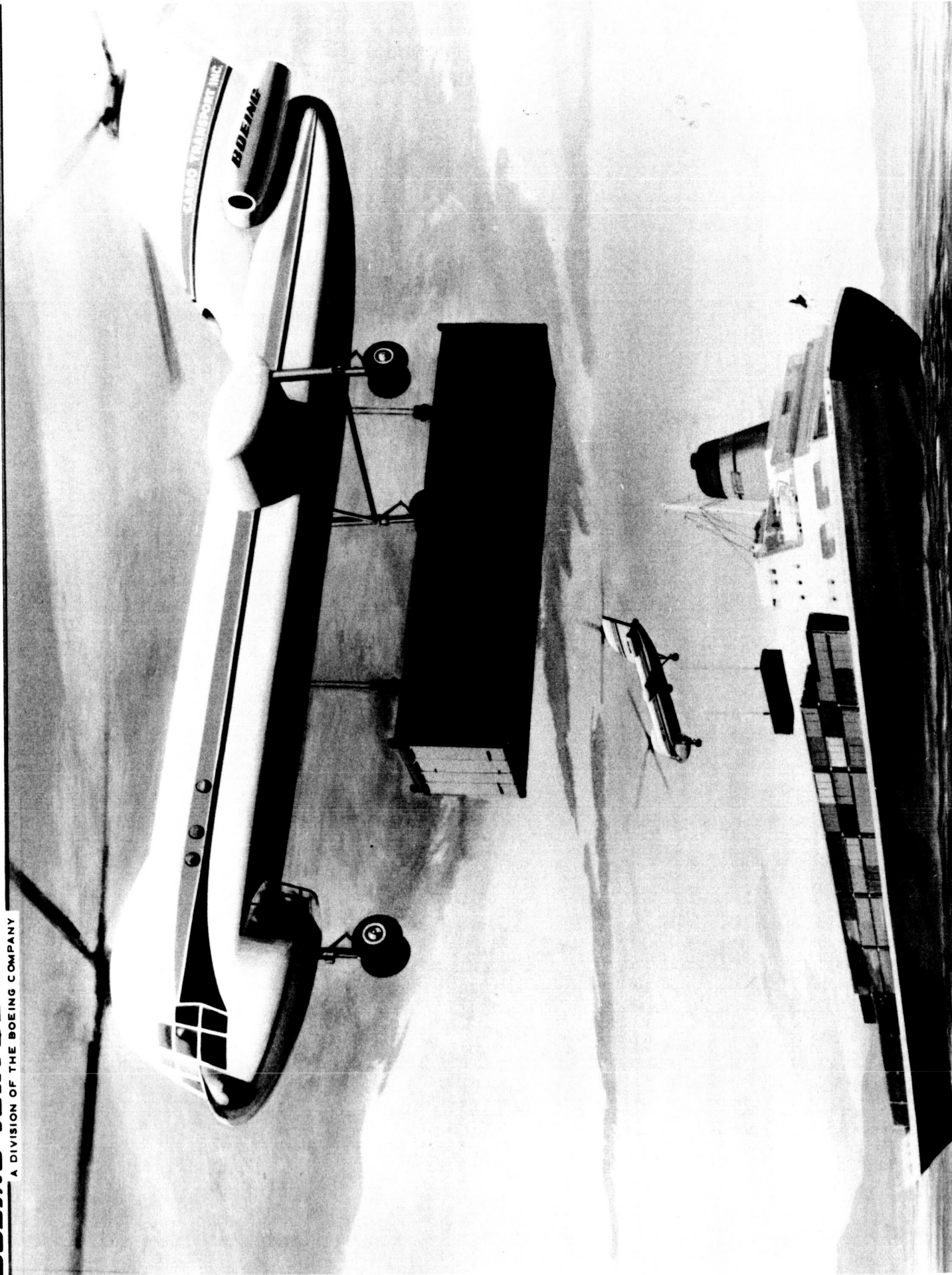
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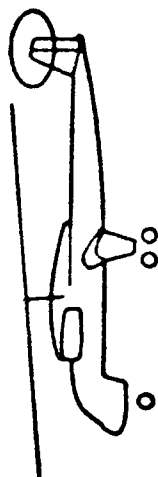
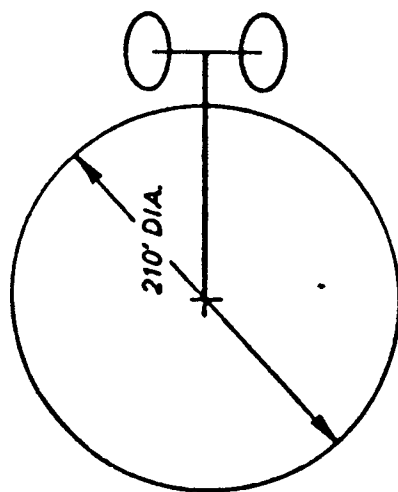


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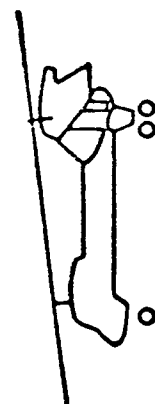
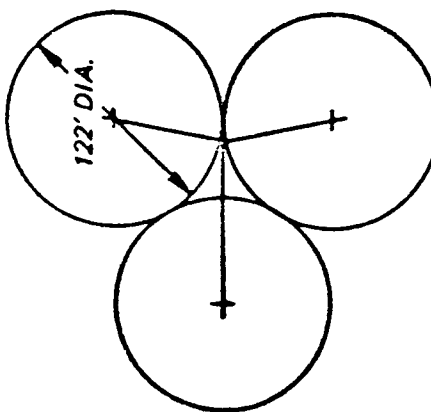




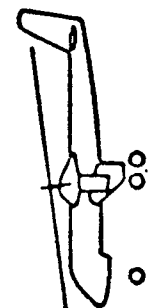
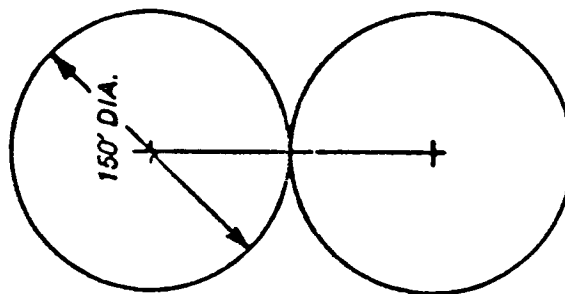
POTENTIAL LARGE ROTOR COMBINATIONS



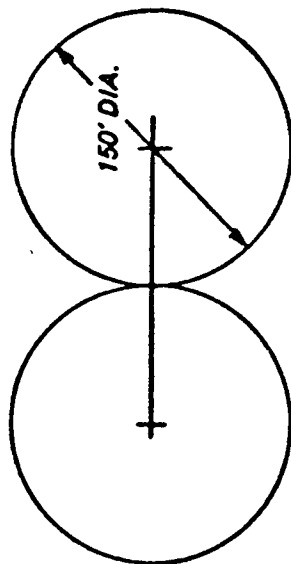
SINGLE ROTOR



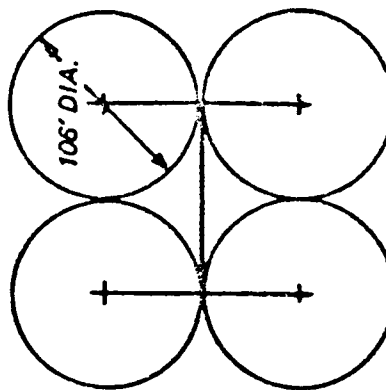
TRI-ROTOR



LATERAL TWIN



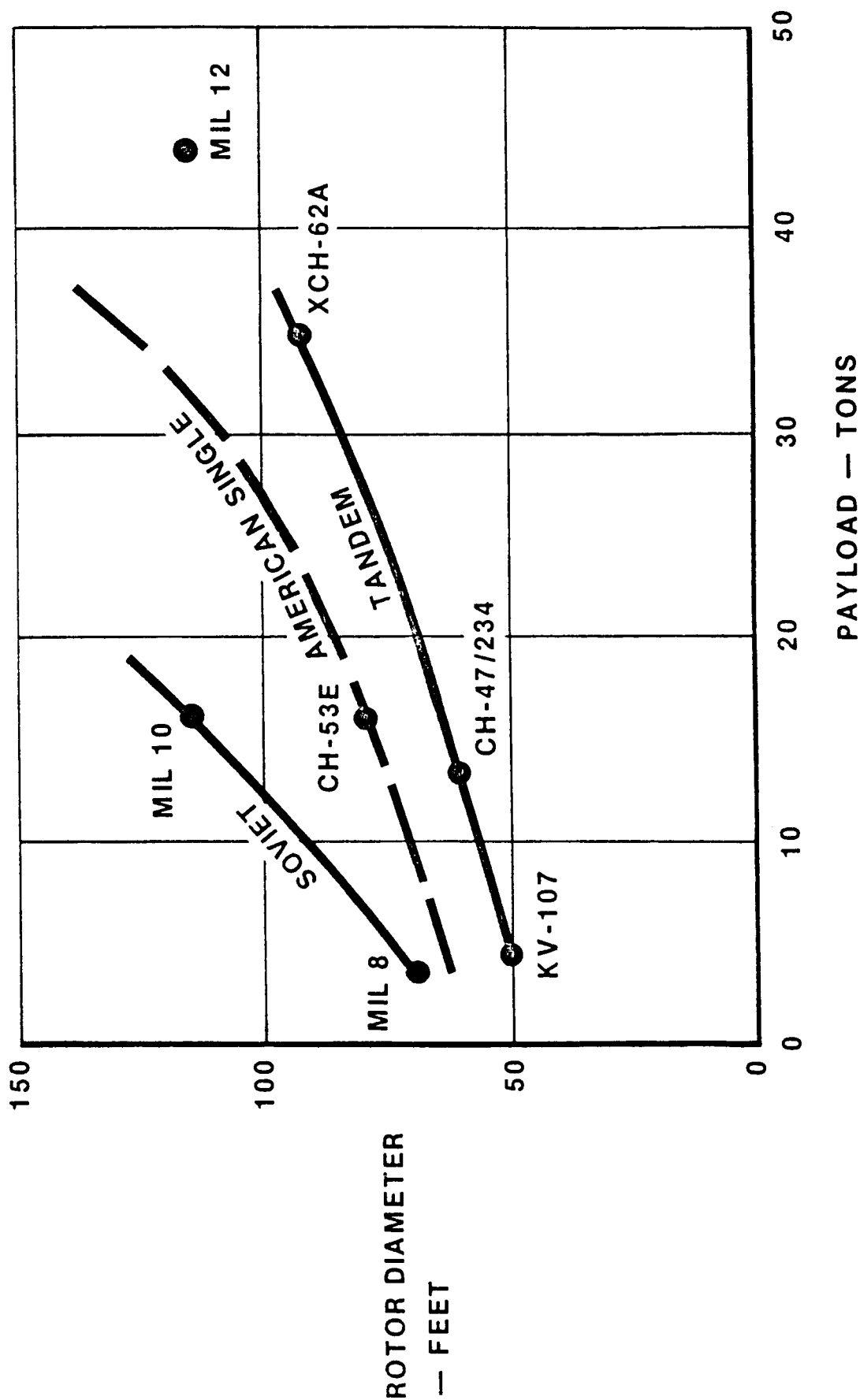
TANDEM ROTORS



QUAD-ROTOR

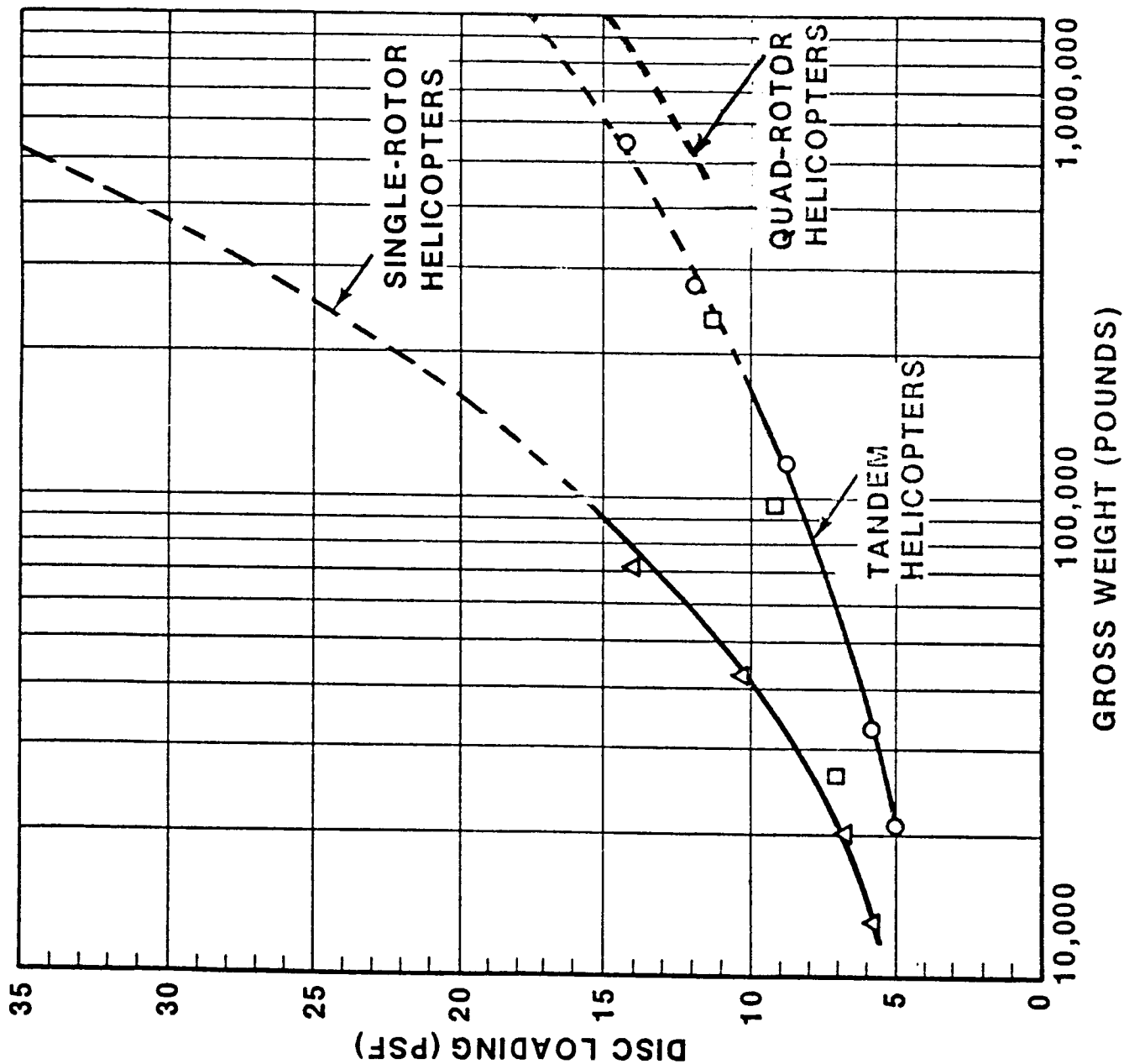
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ROTOR DIAMETER TRENDS

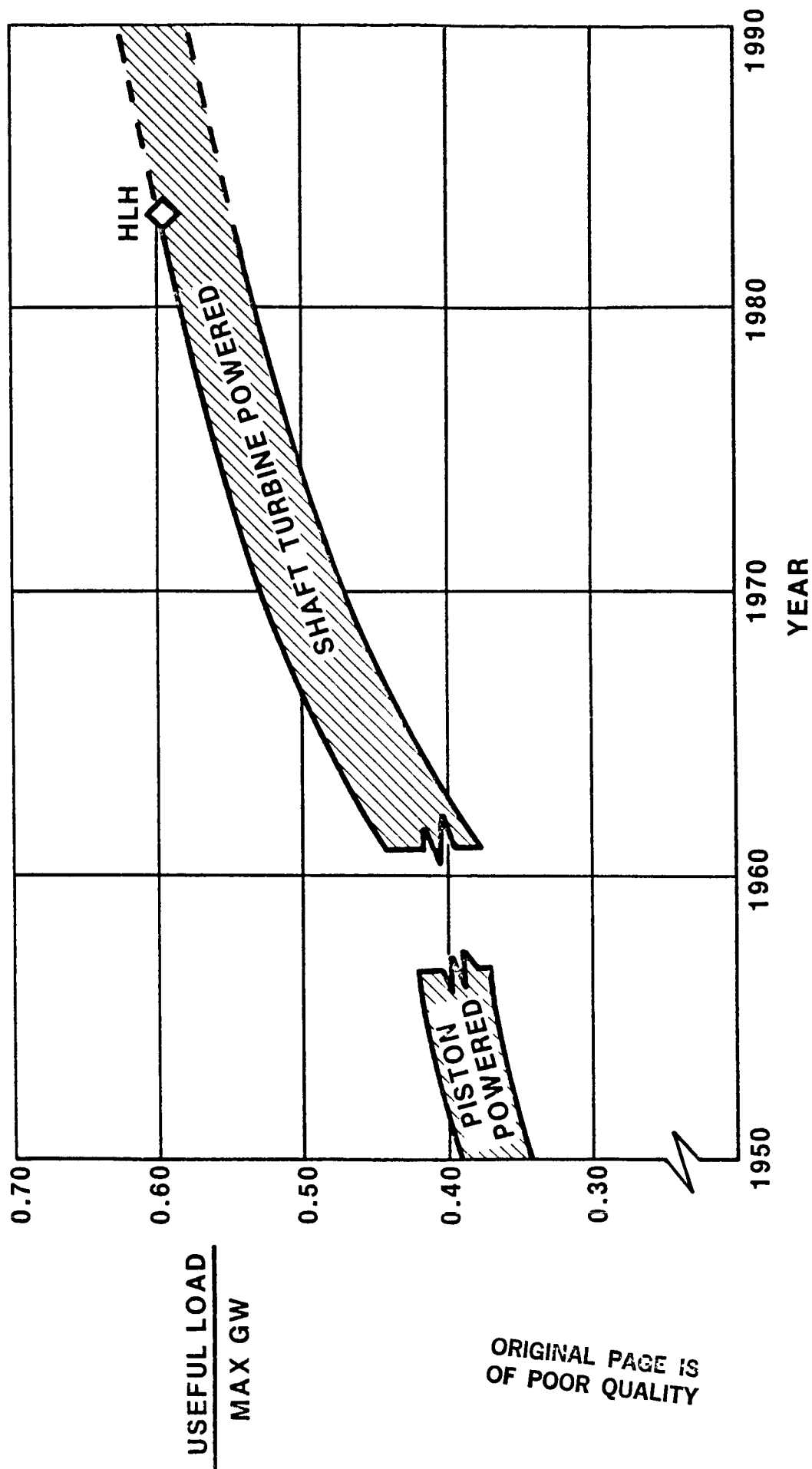


HELICOPTER DISC LOADING TRENDS

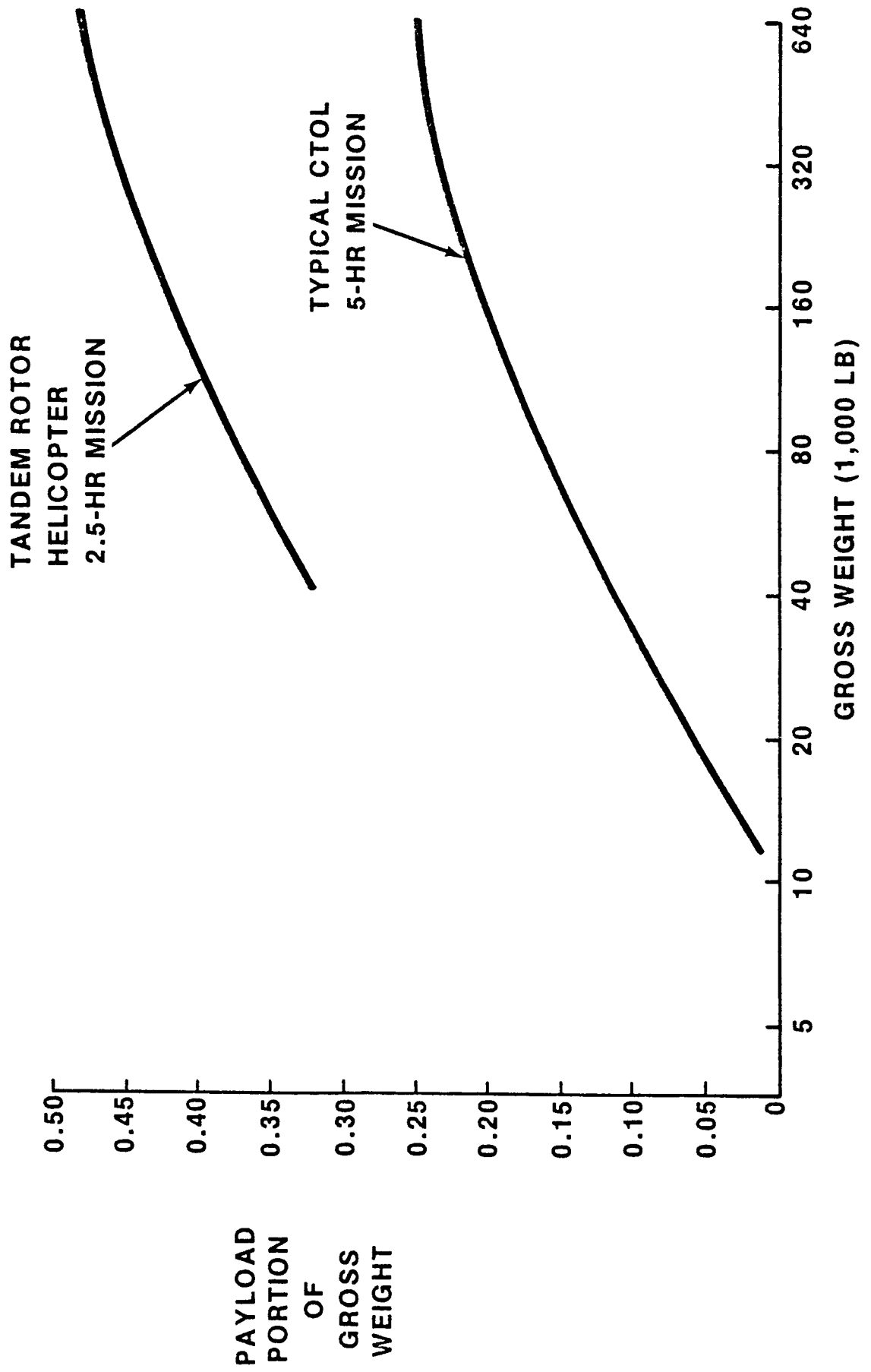
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ADVANCING TECHNOLOGY EFFECTS ON HELICOPTER USEFUL LOAD RATIO



COMPARATIVE PAYLOAD FRACTION



STATUS OF LARGE ROTORCRAFT TECHNOLOGY

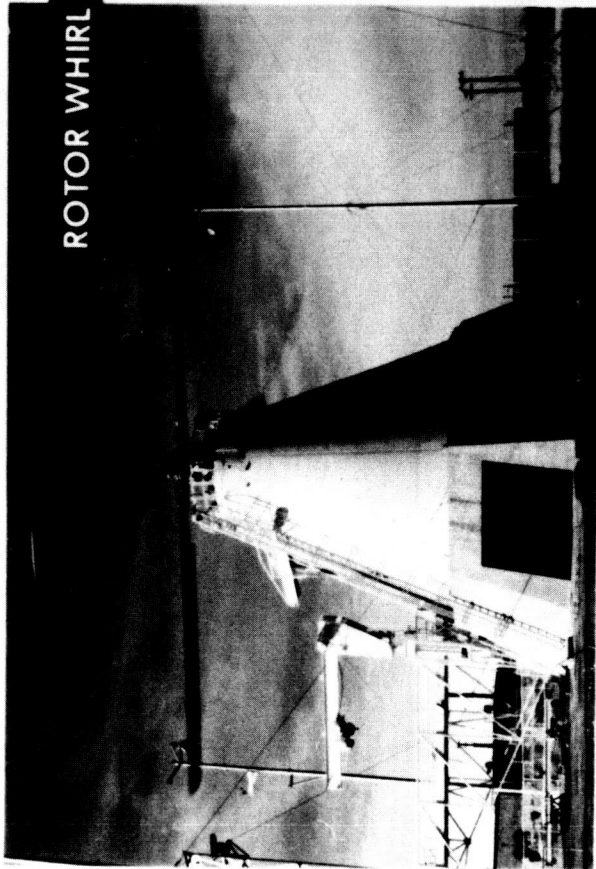
ATC PROGRAM DEMONSTRATED:

- 0 INTEGRATED ROTOR/DRIVE/ENGINE TEST STAND
- 0 FLY-BY-WIRE FLIGHT CONTROLS
- 0 CARGO HANDLING SYSTEM

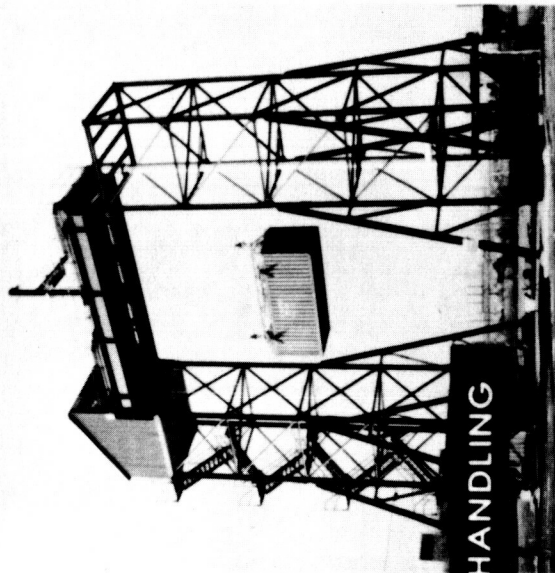
NASA TECHNOLOGY PROGRAM(S) UNDERWAY:

- 0 TRANSMISSION TECHNOLOGY PROGRAM

ATC SYSTEM INTEGRATION TESTING



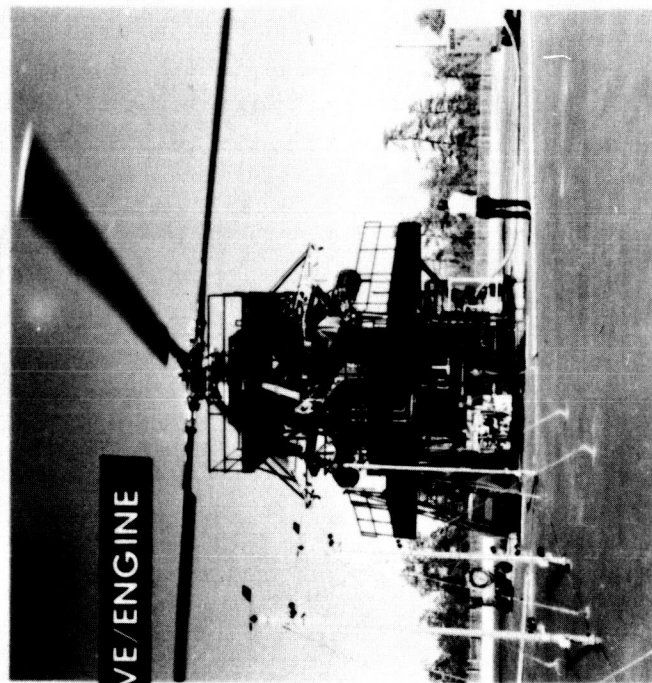
ROTOR WHIRL



CARGO HANDLING

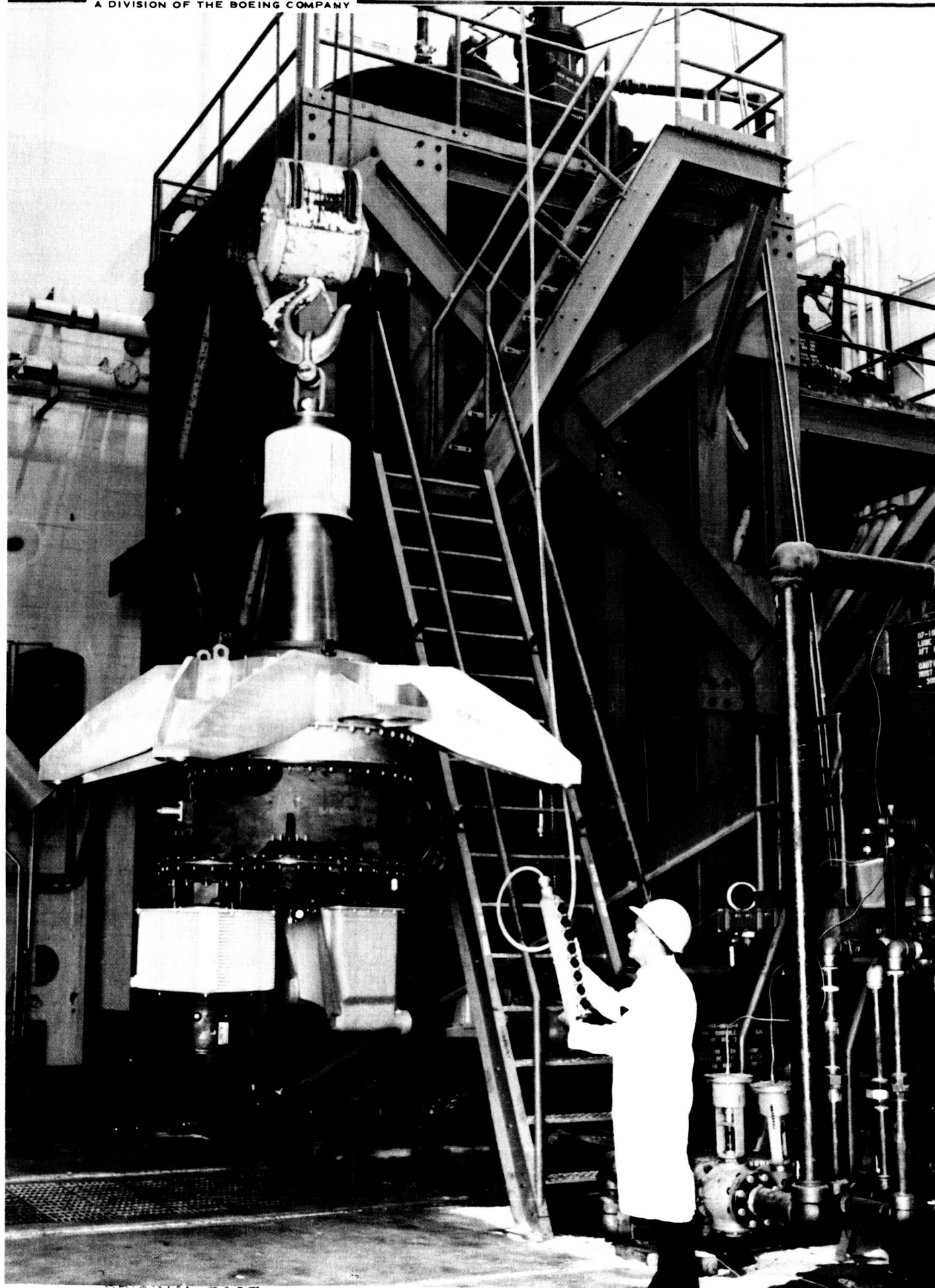


FLY-BY-WIRE FLIGHT CONTROLS



ROTOR/DRIVE/ENGINE





LARGE ROTORCRAFT R&D REQUIREMENTS

EXTENDED TRANSMISSION QUALIFICATION

0 ROTOR TRANSMISSIONS

0 COMBINER TRANSMISSIONS

COMPLETE COMPONENT AND FLIGHT VEHICLE FABRICATION

FLIGHT SUBSTANTIATION

FLIGHT RESEARCH PROGRAM

HLH FLIGHT VEHICLE TEST OBJECTIVES

- TECHNOLOGY DEVELOPMENT OF LARGE HELICOPTER COMPONENTS:
 - Rotor Flight Control
 - Drive Cargo Handling Systems
- EVALUATION OF HONEYCOMB AIRFRAME PRIMARY STRUCTURE
 - Comparison with NASTRAN analysis
- ASSESSMENT OF LOW FREQUENCY VIBRATION ENVIRONMENT
- EVALUATION OF HEAVY LIFT OPERATIONAL UTILITY:
 - 35-Ton Payload Acquisition and Discharge
 - Hover Hold
 - Taxi-over Load
 - Downwash Velocities
 - Ground Interface Criteria
- CRITERIA DEVELOPMENT FOR LARGE PAYLOAD HELICOPTERS

CONCLUSIONS

AN XCH-62 FLIGHT RESEARCH PROGRAM CAN:

- O EXPLORE THE TECHNOLOGICAL ISSUES ASSOCIATED WITH
LARGE HELICOPTERS
- O PROVIDE A TECHNOLOGY DATA BASE FOR FUTURE PROGRAMS
- O LOWER THE RISK OF FUTURE LARGE HELICOPTER DEVELOPMENT
- O EVALUATE MISSION SUITABILITY
- O REESTABLISH U.S. PREEMINENCE IN HELICOPTER VERTICAL
LIFT CAPABILITY

HEAVY LIFT PANEL DISCUSSION

BY

F. N. PIASECKI, PRESIDENT
PIASECKI AIRCRAFT CORPORATION, PHILA., PA

Heavy lift started back in 1946 when the first tandem transport helicopter, the Piasecki XHRP-X, picked up a 1,800 lb. log, (Fig. 1). Two lines lifted the log and one of the fellows up front is me. The photographer had to be fast on his feet because the scene didn't last very long -- about a second. We dropped the log because we began to feel the moments imparted into the aircraft as the log began swinging. This was with two long lines, -- which appeared to be a logical way to spread the load to the fuselage. But there it was circling us, and we dropped the log fast and went back to a single line located close to the aircraft's center of gravity. This original lift capacity was multiplied by new designs: The Piasecki H-21 (5,200 lbs.), the Piasecki H-16 (13,000 lbs.), the Sikorsky Sky-Crane (20,000 lbs.), the Boeing-Vertol Chinook (28,000 lbs.), and the Sikorsky CH-53E (32,000 lbs.).

A long lull in heavy lift helicopter development has passed since the abortive Boeing-Vertol XCH-62 project that has yet to fly when more funding can be supplied. Perhaps this was because there was no available economical way to get a truly heavy lift. By "heavy", I mean the 62-ton Main Battle Tank that the Army used as a goal.

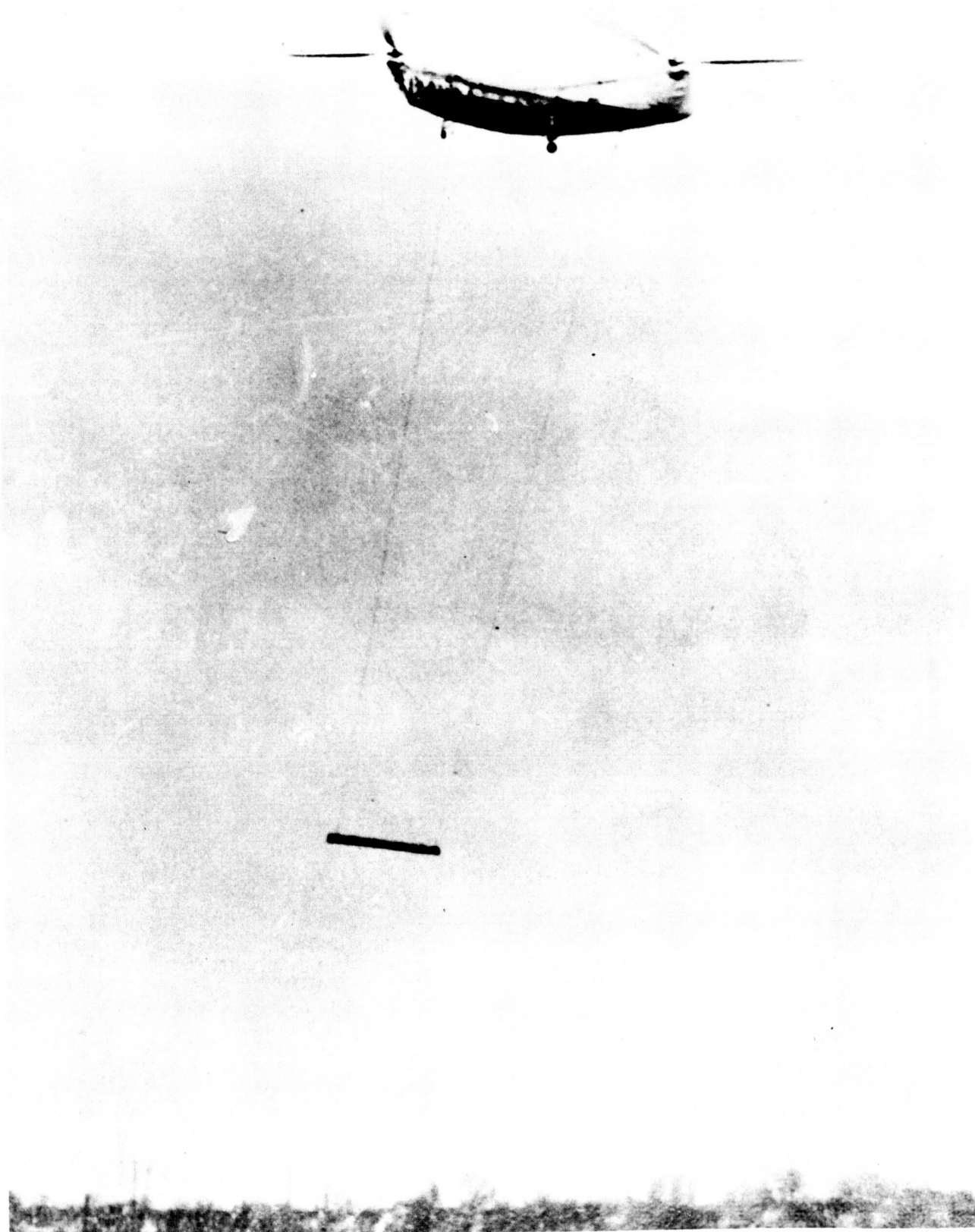


FIG. 1 FIRST TANDEM HELICOPTER, XHRP-X, LIFTING 1800 LB. LOG
ON TWO 125 FT. LINES -- 1946

VI-230

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In 1958 we were approached by a South American who had a heavy lift job to do beyond the capacity of existing helicopters. We responded with the concept of joining a couple of helicopters together and adding a balloon to get a heavier lift than by helicopter alone. He never came back.

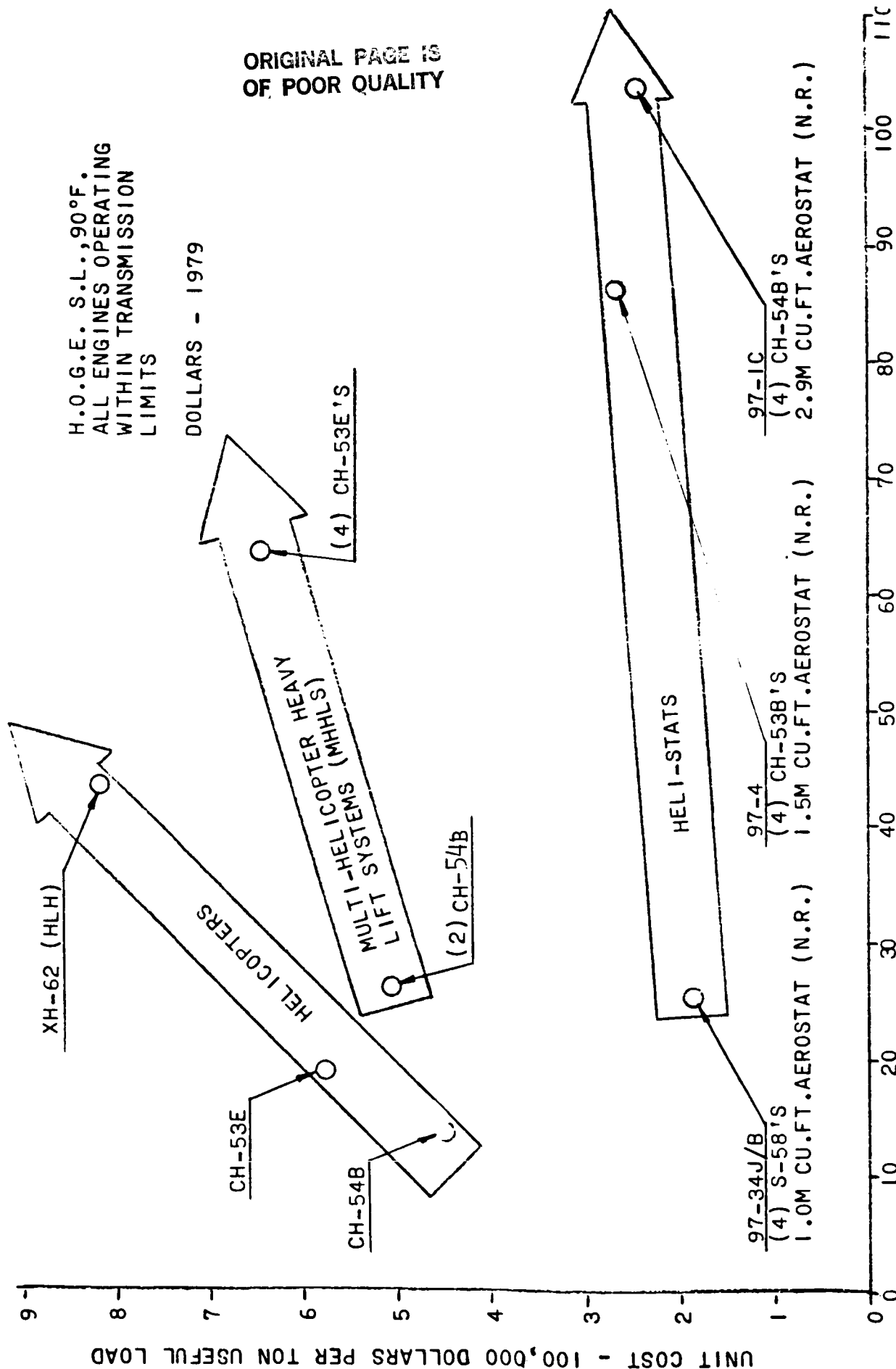
As larger helicopters were built, it became evident that what was happening with the increase in size of helicopters was a nonlinear increase in unit cost per unit useful load. (Fig. 2) roughs out this relationship. Don't consider these numbers exact, but that's the relative position of them. Again, the factor that was brought out here earlier that if you make helicopters smaller you can make more of them and buy them at reduced cost, but as you make them bigger to pick up larger loads you get less of them which adds to their cost.

So we started to think in terms of how to stop this reversal of economy-of-scale beyond certain sizes. It can be done by brute force if you have enough money. Apparently, the Army didn't have enough money when it got to the XCH-62 size and cancelled the program. Multiple lift by coordinating two or more individual helicopters to pick up a single load seemed attractive but pilots didn't quite like that idea of being tied to a load. So at Piasecki we thought in terms of attaching multiple helicopters to be operated by one pilot, such as the four CH-53's (Fig. 3).

H.O.G.E. S.L., 90°F.
ALL ENGINES OPERATING
WITHIN TRANSMISSION
LIMITS

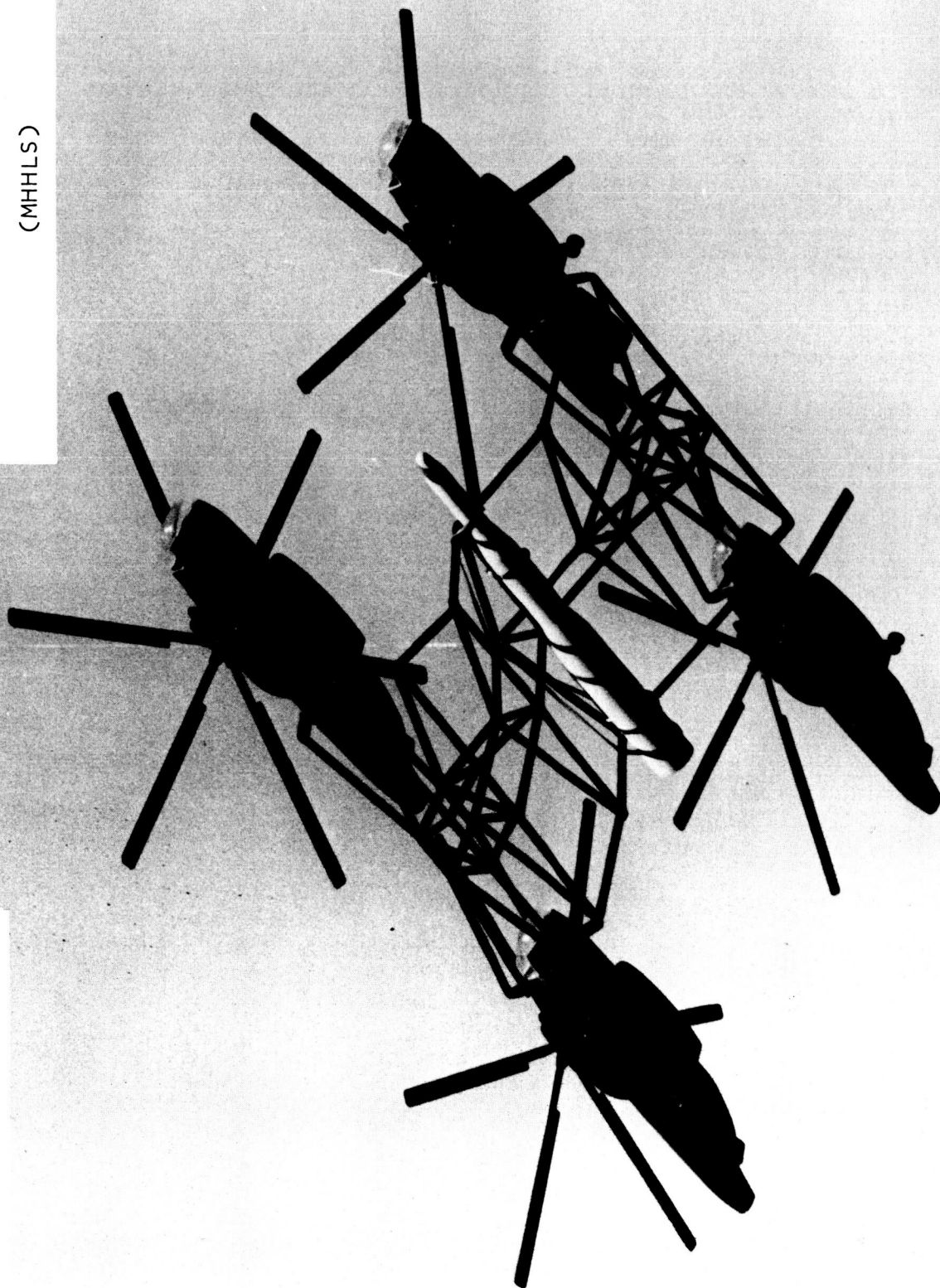
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DOLLARS - 1979



RELATIVE ACQUISITION COST PER TON OF USEFUL LOAD OF HEAVY VERTICAL AIR LIFT SYSTEMS

FIG. 2



PIASECKI MHLS 39

FIG. 3

It doesn't take much of a jump to go from there to add a static lift device which can reduce the weight empty to zero, and create a hybrid configuration (Fig. 4) which goes back to our 1958 patent application. Returning again to (Fig. 2) the chart illustrates comparative costs of single, multiple, and hybrid type configurations. For example, four Sikorsky CH-53's linked together could lift the 62-ton Main Battle Tank. It may not generate aesthetic appeal, but it is a solution to the 62-ton lift, and it can be done cheaper than by developing a single 62-ton payload helicopter. This lull in helicopter development has been in great part chargeable to the "riskless" attitude on the part of our government committees or whoever holds the public purse strings.

The first helicopter to fly (Breguet, 1907) was in fact a four-rotor machine (Fig. 5). The first helicopter to fly in the United States (DeBothezat, 1922) was also a four-rotor machine (Fig. 6). A four-rotor machine was built in France (Oemichen, 1924) that had four main rotors (Fig. 7). David Kaplan built and flew a four rotor machine in the 1950's (Fig. 8). Piasecki built a four-rotor, dual-tilting helicopter as an omni-directional drone that flew only on autopilot (Fig. 9).

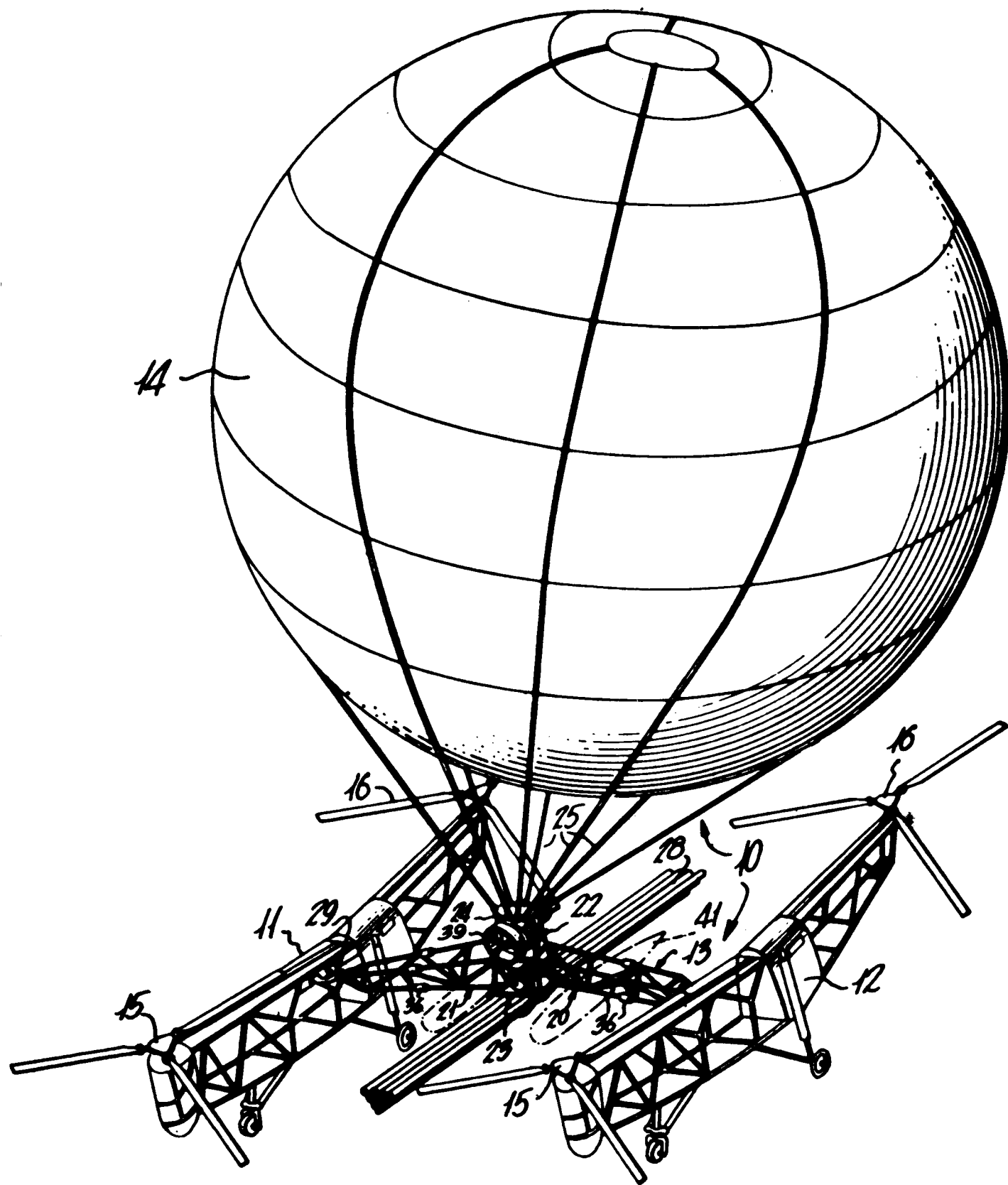
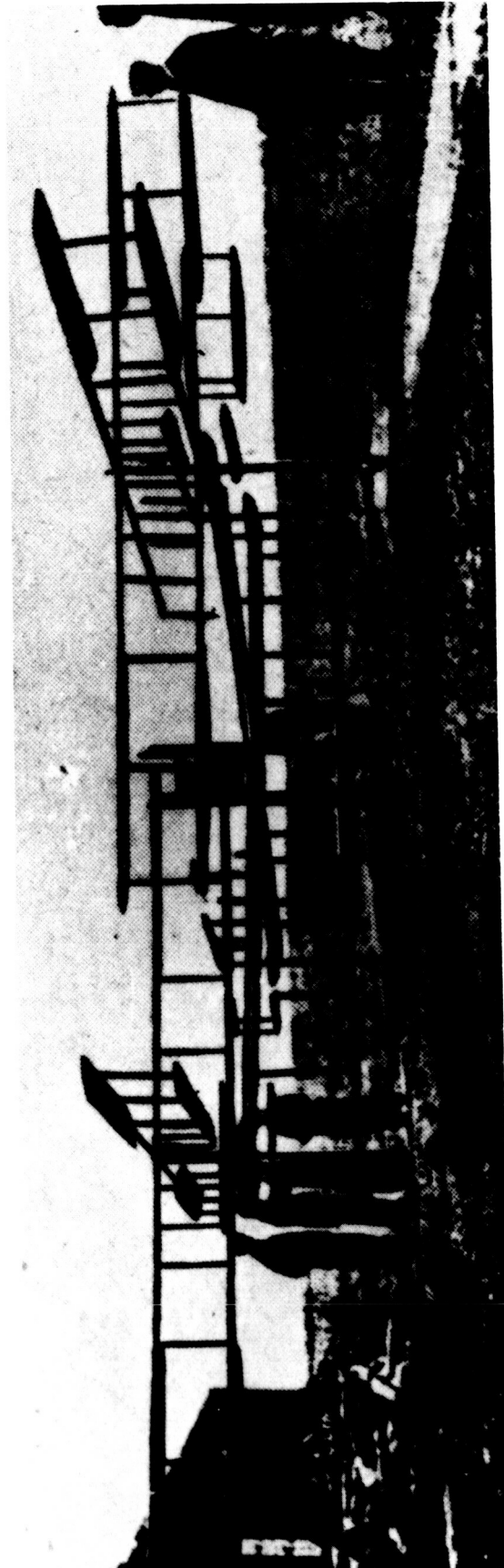


FIG. 4

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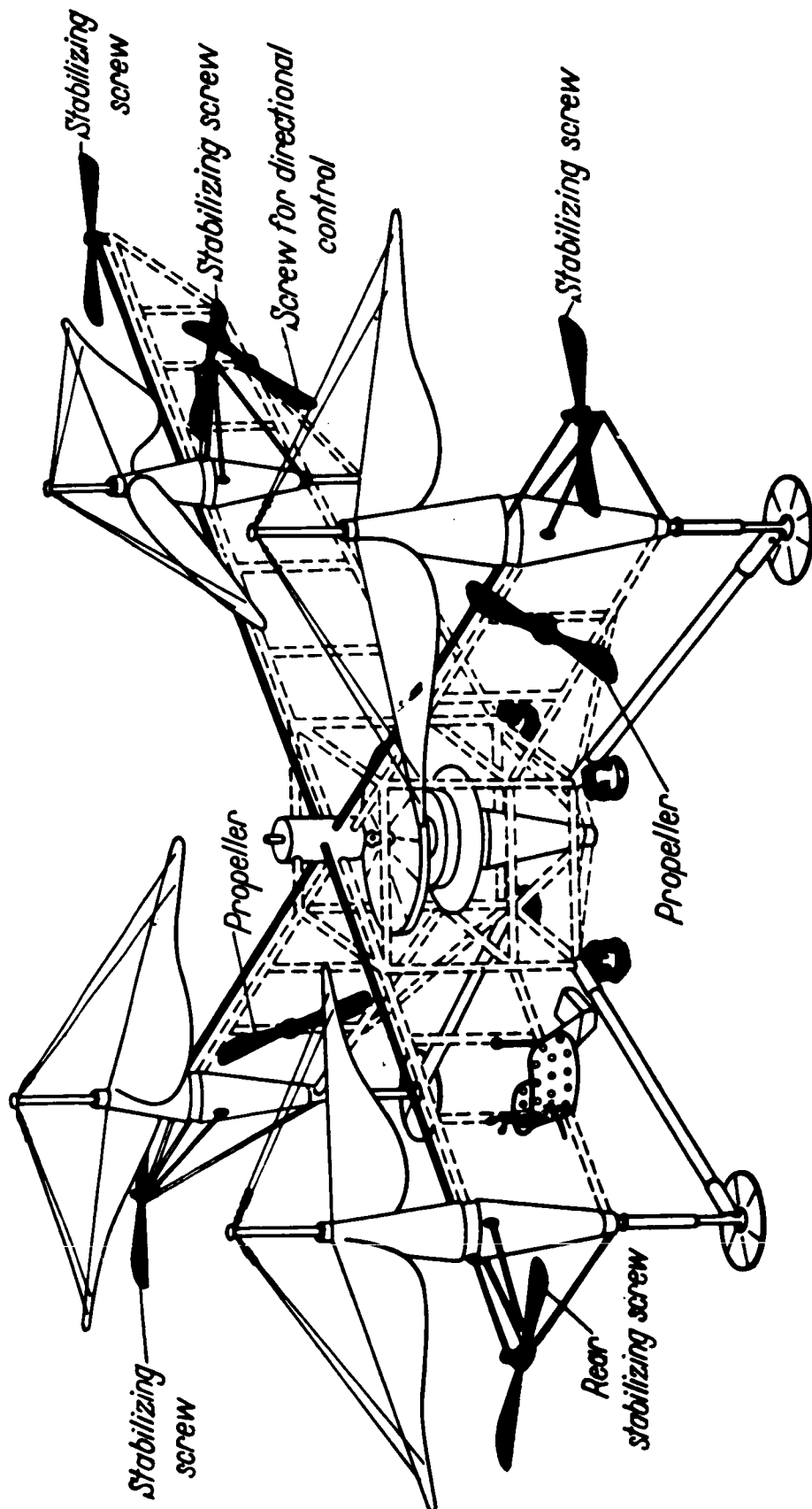
Breguet-Richet—1907

FIG. 5



De Bothezat

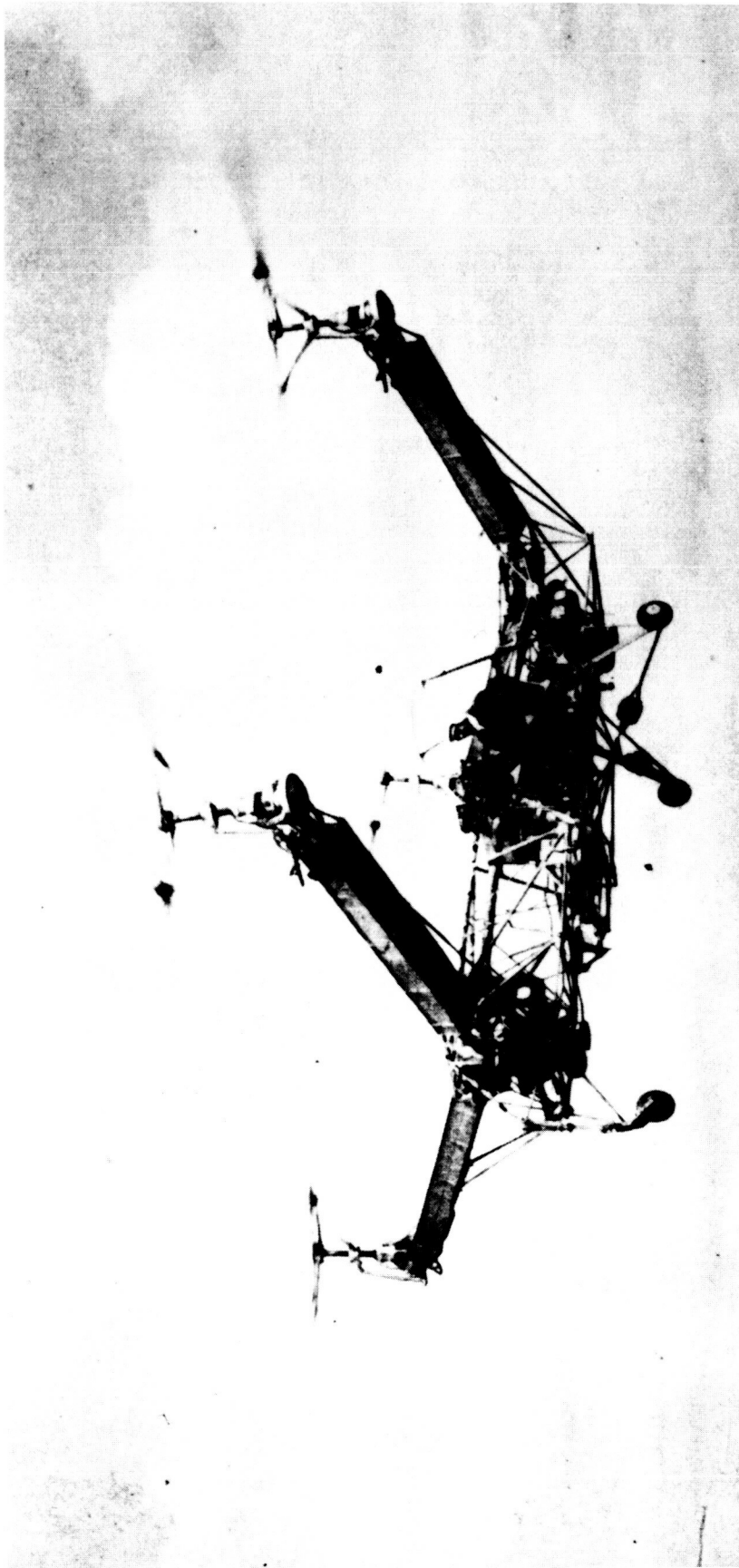
FIG. 6



Oehmichen

FIG. 7

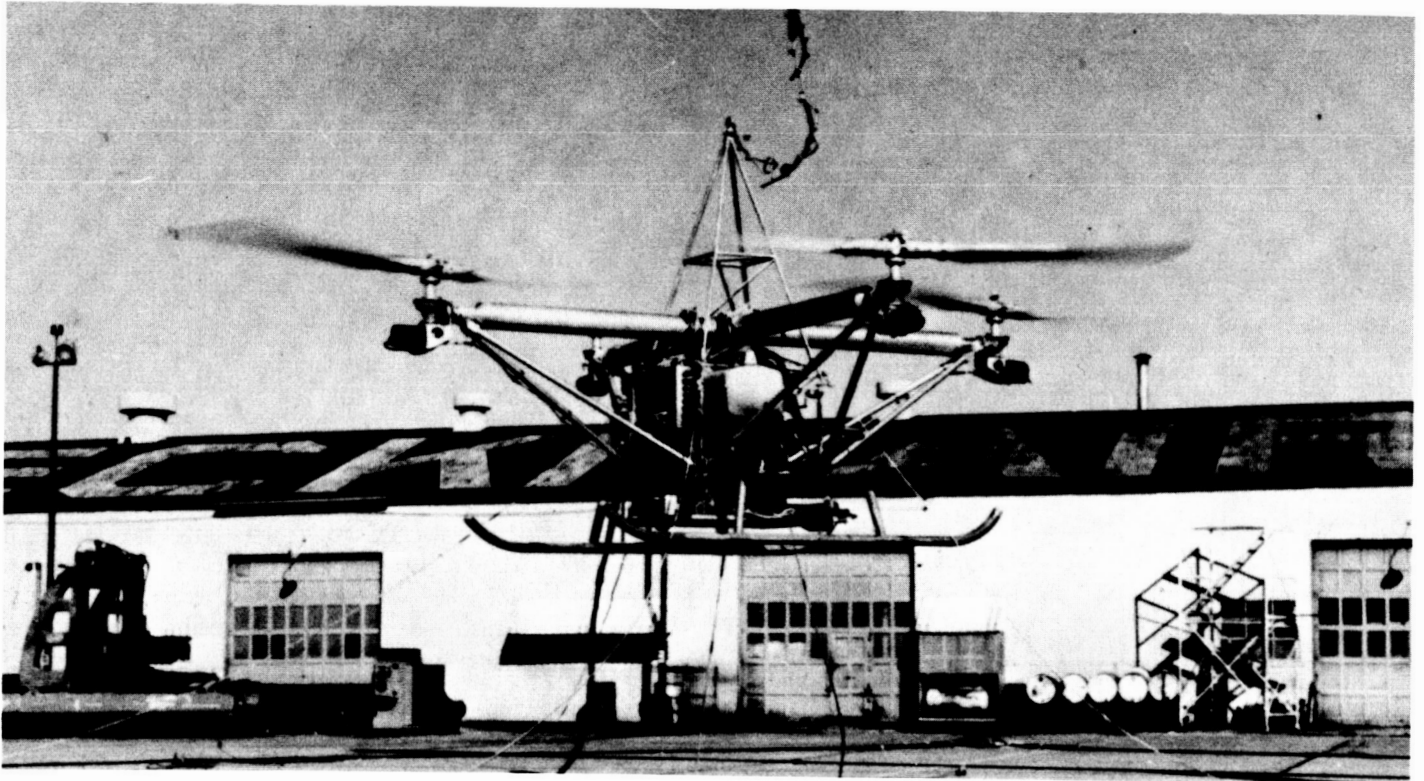
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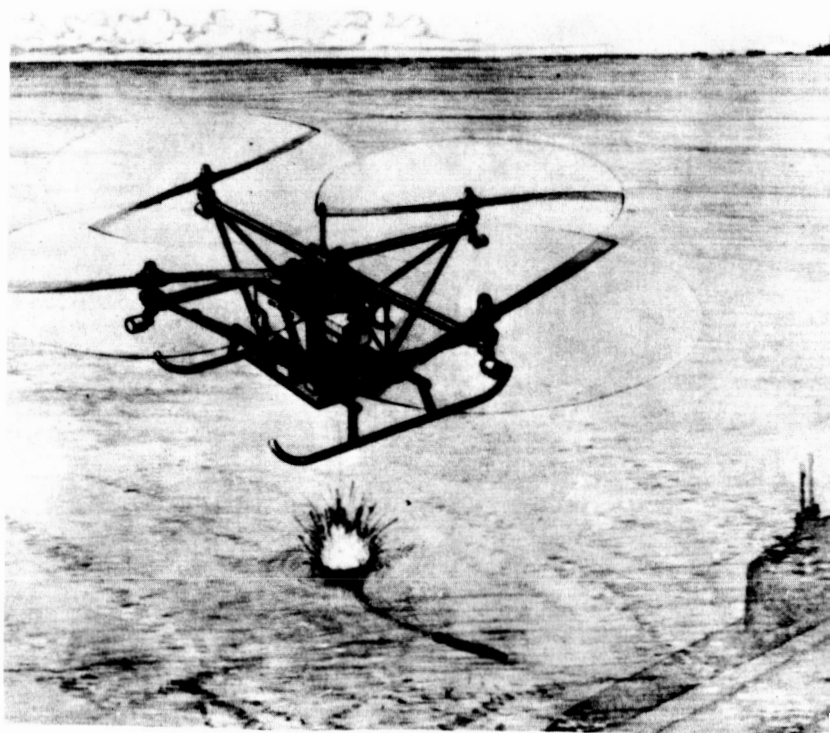
HOVERING OUT OF GROUND EFFECT, 360-deg. turns, forward and rearward flights have been made by Convertawings' Model A.

FIG. 8

MODEL PA-4 "SEA BAT" FIRST UNMANNED OMNIDIRECTIONAL DRONE VTOL



PA-4 "SEA BAT" FIRST FLIGHT: 25 OCTOBER 1958



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ARTIST'S SKETCH OF "SEA BAT"
PERFORMING ASW MISSION

To show the effects of downwash on hovering stability, the Army flew four CH-54's in formation to determine the relative effect of the downwash reflecting from the ground back up into the helicopters (Fig. 10). So the four-rotor configuration is not an untried system and has many advantages in design.

Piasecki Aircraft has studied a family of multi-rotor designs with the objectives to increase lift capacity and to lower cost by utilizing production helicopters. Piasecki project 39-4-53-E takes four of the Sikorsky CH-53E helicopters less their tail cones and props, landing gear, and other equipment and interconnects the controls and drive systems with a new truss structure in order to lift the Main Battle Tank.

From this configuration, the concept of adding static lift by attaching a helium filled envelope to the interconnecting structure was a logical step. This hybrid of dynamic and static lift is called the Piasecki "Heli-Stat" which is what we are building right now in Lakehurst, New Jersey (Fig. 11). It connects four Sikorsky H-34 helicopters and adds four pusher props, not tail rotors, and the load is either snugged or suspended. The H-34's are all interconnected, both control-wise and drive system via two diagonal shafts. This model, the 97-34JA has a maximum useful load of about 28 tons.

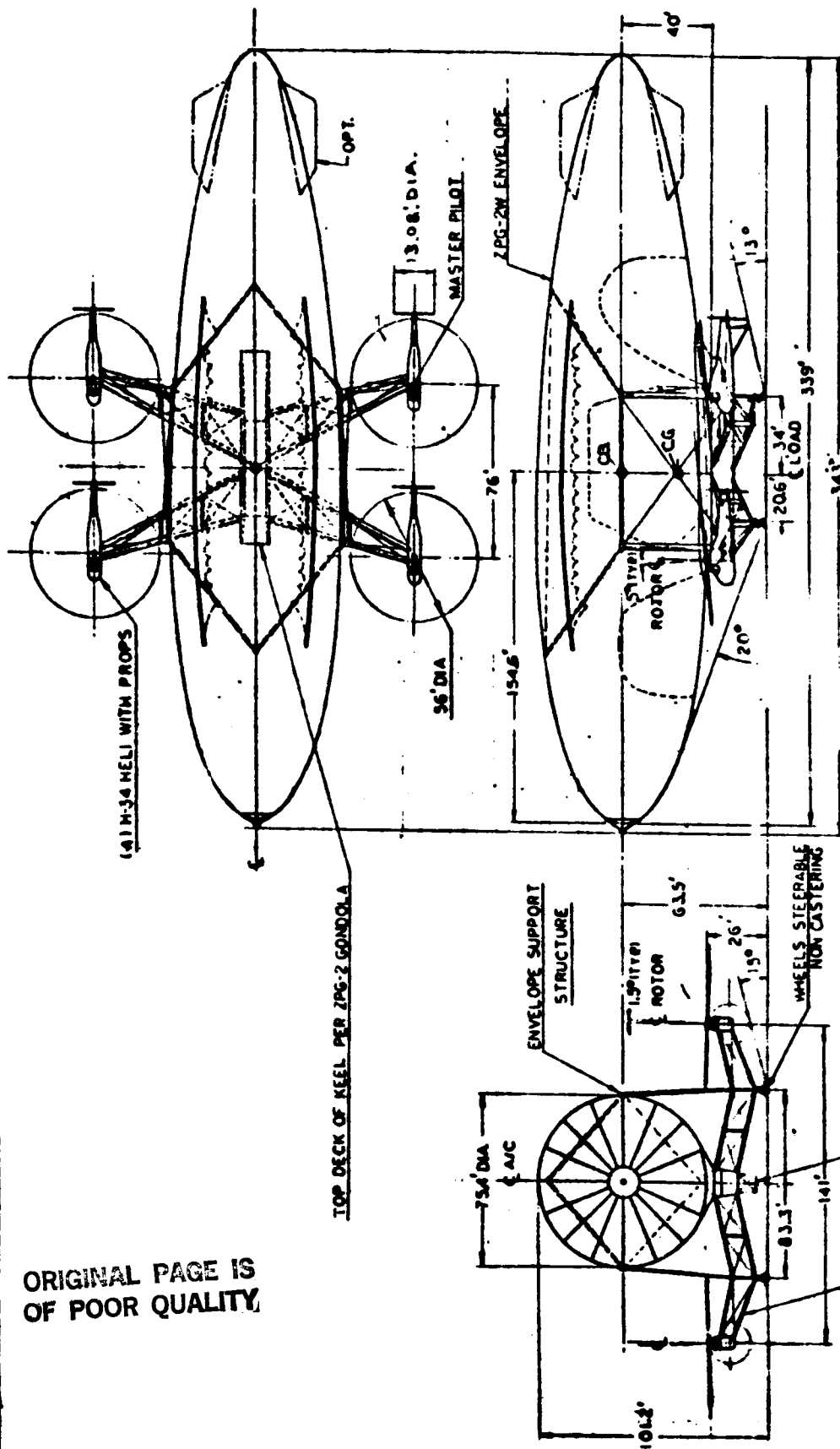
One interesting advantage of hybrids is low downwash. (Fig. 12) shows helicopter CH-53E downwash at various distances above the ground in terms of dynamic pressure.



FIG. 10. (4) CH54B HELICOPTERS HOVERING IN GEOMETRIC RELATIONSHIP

PER THE HELI-STAT DESIGN, 97-1C

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HELIP-STAT		Plastic Account
MODEL 97-34JA		
ZPG-2W ENVELOPE		0150 97X0060 2
(41H-34 HELI WITH PROPS)		

FIG. 11

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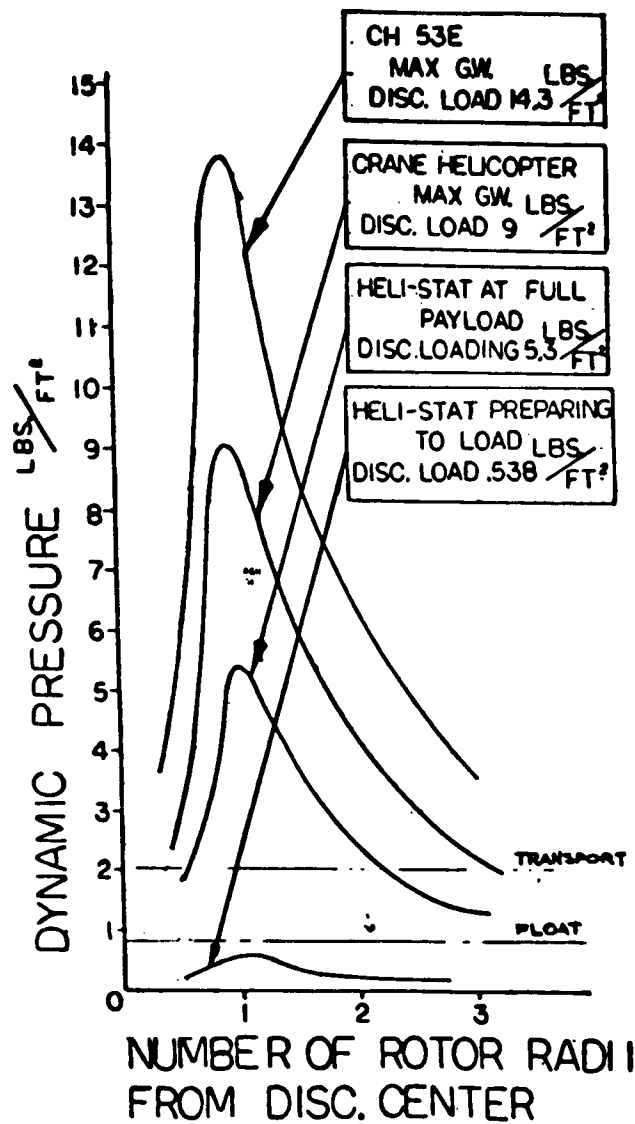


FIG 12. DOWNWASH

The "Heli-Stat" at full payload has the same rotor disc loading as the H-34. However, when approaching to pick up a load, there isn't even enough downwash to air float sand. So for the first time, we have a low disc loading which gives us high visibility during load attaching and low noise. Of course, when the load is attached and lifted, the "Heli-Stat" will have the same magnitude of downwash as the helicopter rotor of the same loading except that it will be around the load and directly on it as it is with a helicopter.

The "Heli-Stat" fabrication at Lakehurst (Figs. 13 and 14) show the two helicopters position relative to the bag to give an idea of the overall scale.

Our first "Heli-Stat" application is to demonstrate improved economics in timber harvesting for the U.S. Forest Service. Eventually, there will be other applications, and larger "Heli-Stat" models that can carry over 85 tons.

Attractive economics carry over into military requirements. (Fig. 15) shows two comparisons of the various means of transport "over the shore." The lower bar chart indicates the relative load capacities and the upper, the life cycle costs. The LACV-30 is an air cushion, 30-ton container carrier. The XCH-62 is shown at 22-1/2 tons, and existing water borne lighters are shown in relative comparisons.

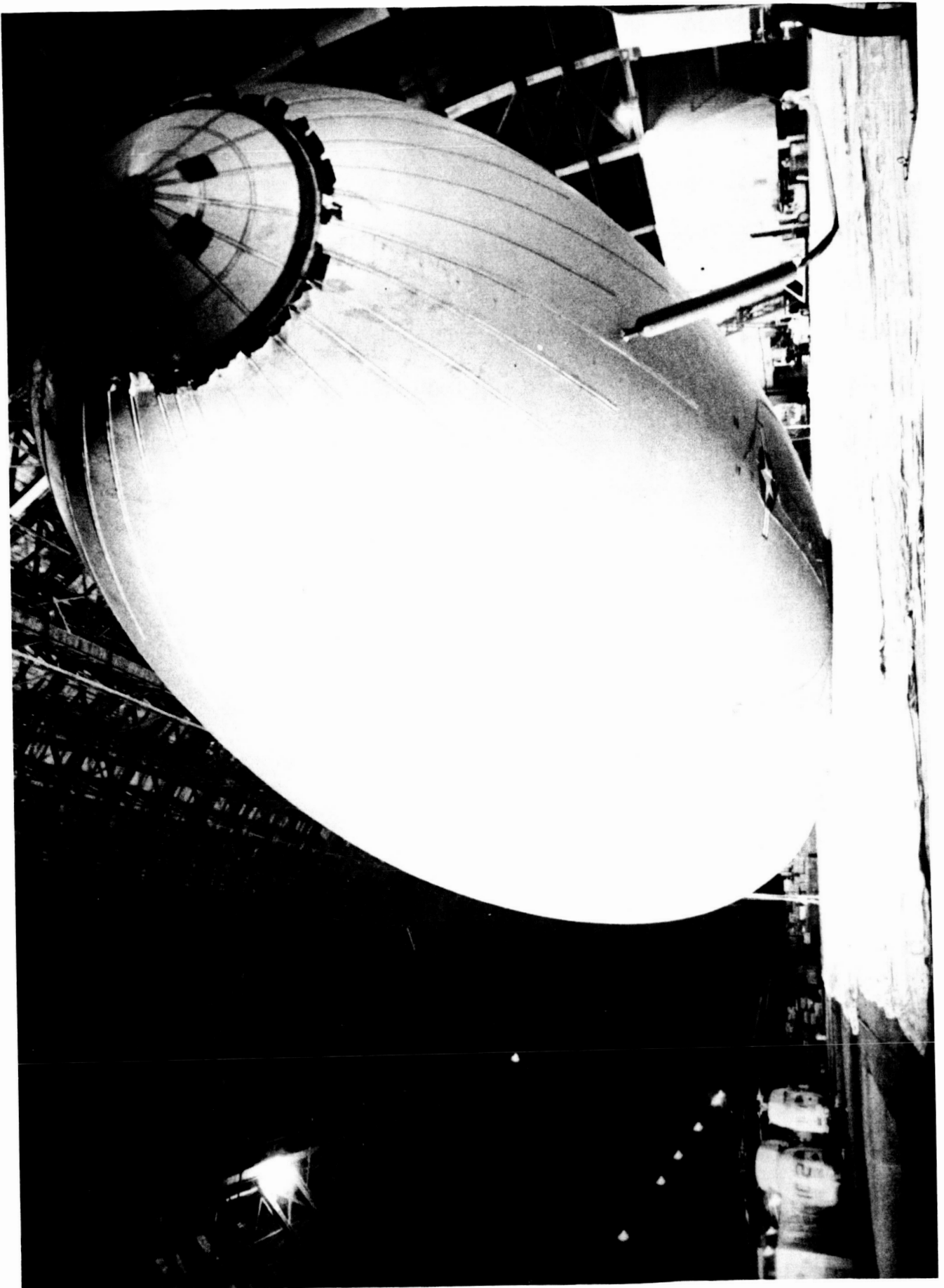


FIG. 13

VI-246

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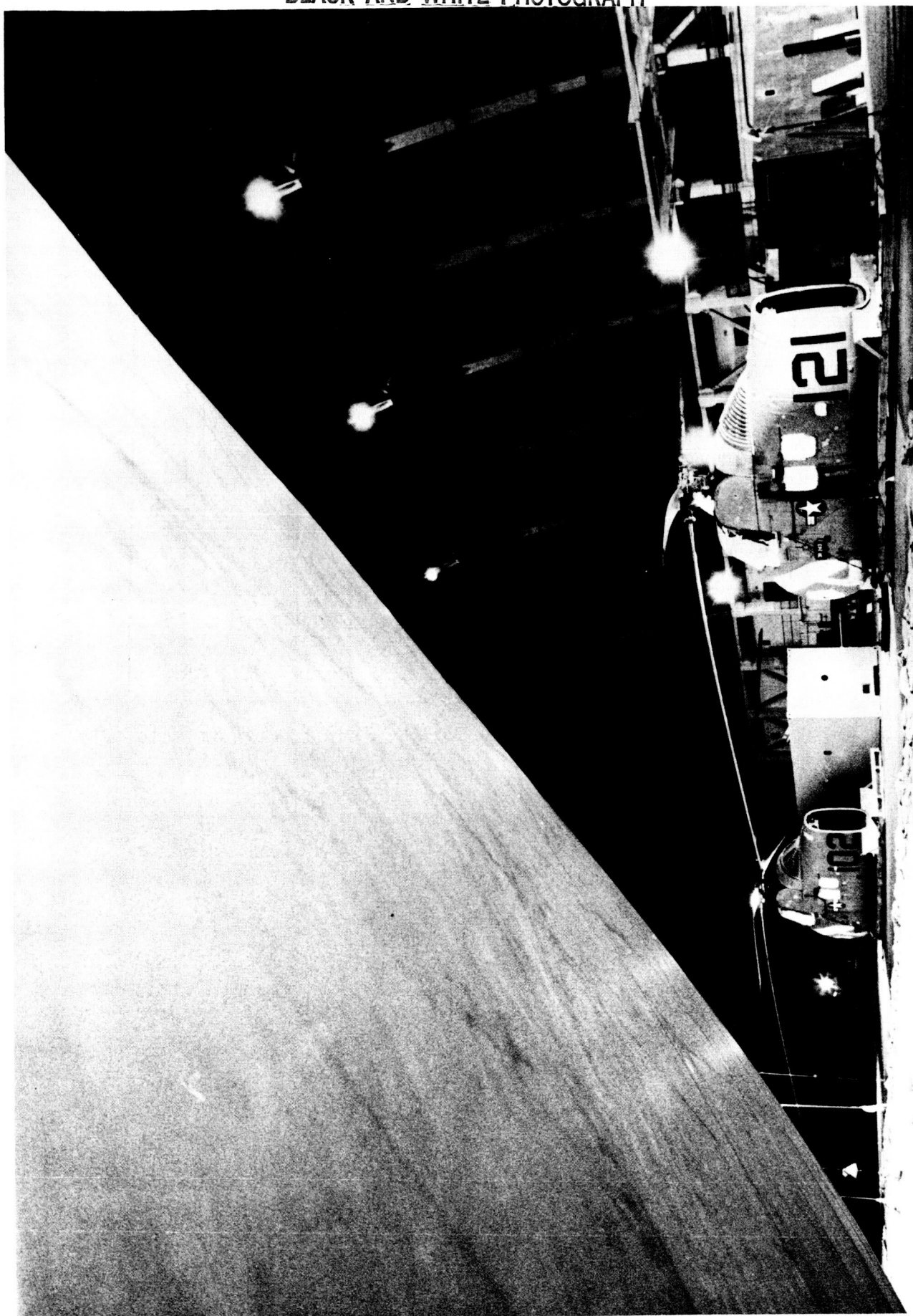


FIG. 14

VI-247



SHIP UNLOADING LOGISTIC
SYSTEM COMPARISONS

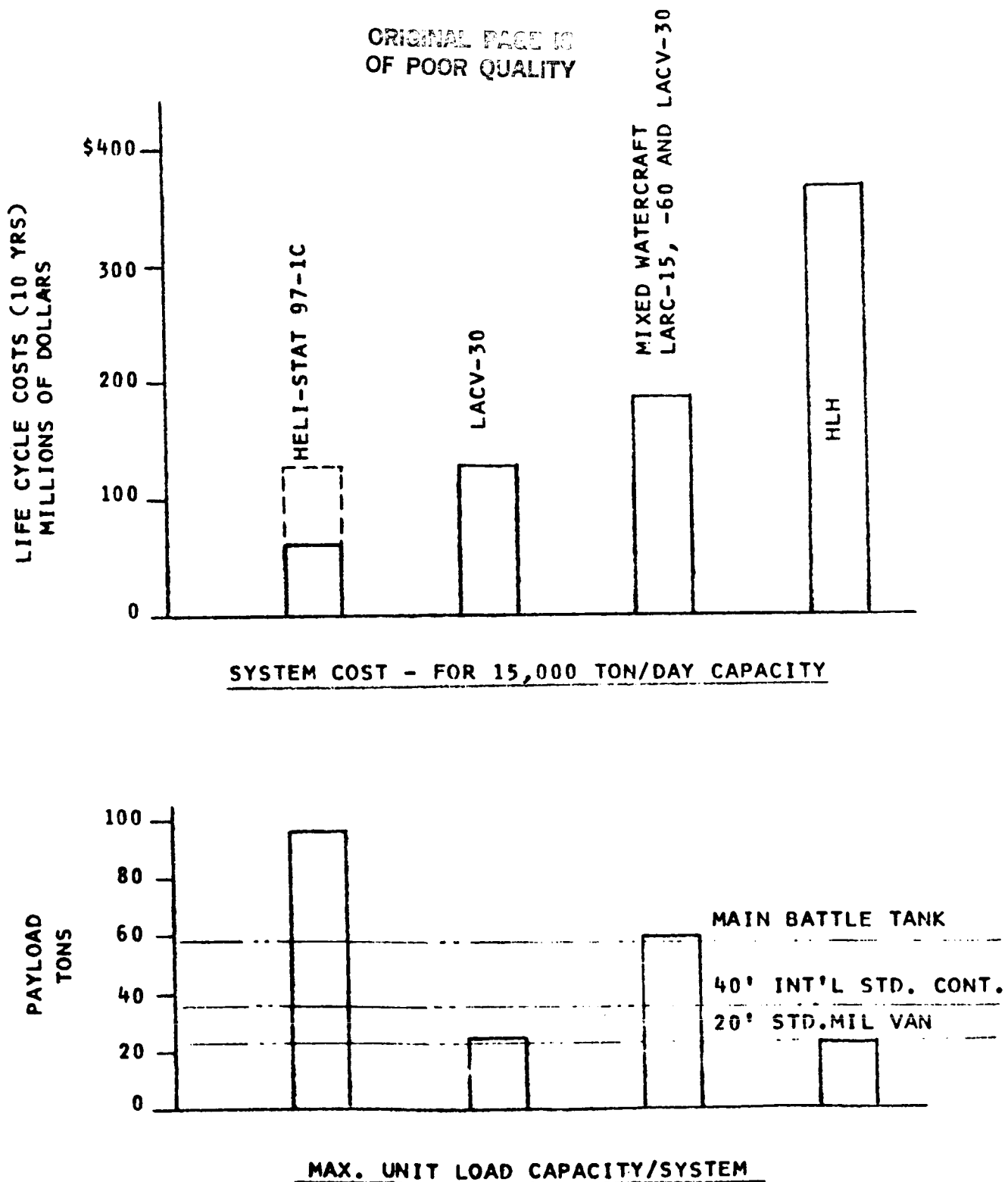


FIG. 15

The LACV-30 can't lift the Main Battle Tank, therefore, a new ground effects machine of 62-tons capacity would have to be designed. The ground effects machine is not the lowest cost even at the 30-ton size.

(Fig. 16) is a general matrix of transportation options presenting a series of mode combinations.

Most transport functions are done in one stage length and most always involve intermodal operations. For instance, in the timber harvesting problem, the economical distance for air transport in inaccessible forests today is only about 1-1/4 miles. We hope to get it up to about six miles with the "Heli-Stat". Then the timber is transferred to highway or river for transport to the saw mill.

I really believe NASA should make material available on the following:

1. The wonderful work it has done on airfoils with a new total data package which would be highly desirable for design engineers throughout the country.
2. The aerodynamics of bodies of revolution similarly. A lot of work has been done on this but a lot more remains to be done. Particularly mooring moments of bodies of revolution near a ground plane and tail effectiveness near a ground plane. NASA

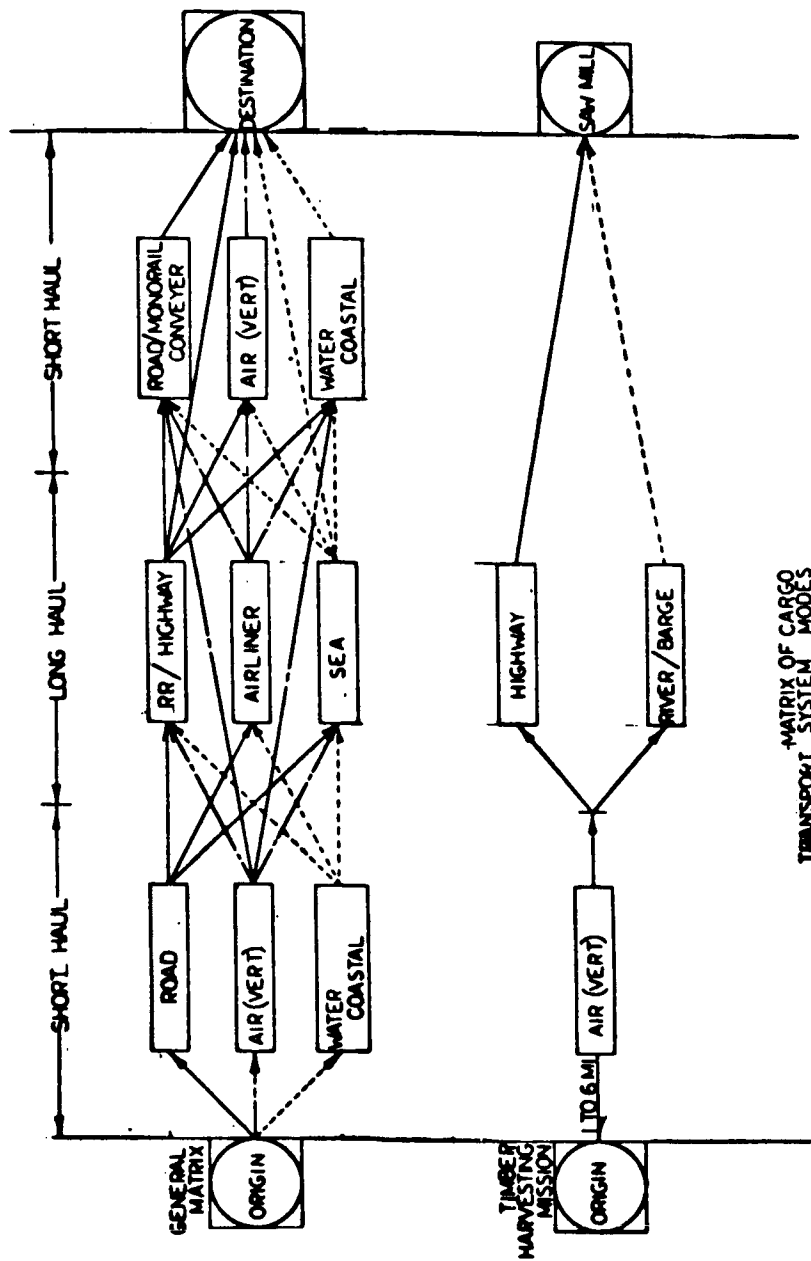


FIG. 16

has looked at some aerodynamics of rotor positions relative to envelope geometry. But the scale and the measurements have to be such that they can be fairly well established and confirmed by testing.

3. Full-scale tests of ducted propellers and control vanes require more testing, particularly with large turning angles of the exit flow.
4. Research on rip-stop fabric assemblies and fabric combinations.
5. Cockpit simulation of the vehicle's controllability and maneuverability.
6. Large hangar structure design and aerodynamic testing to reduce cost and operational limitations.

QUESTION

How many pilots fly the machine and how do you size the bag?

ANSWER

The system is four rotors interconnected; controlled by one pilot. You could put no balloon, or you could put a little balloon, or you could put one that's exactly equal to the weight of everything so your weight empty is zero. Or you could go beyond neutral buoyancy and put a bigger envelope that would require you to carry ballast.

QUESTION

Does the "Heli-Stat" carry ballast?

ANSWER

No. We're always heavy.

Incidentally, I would like to make a general comment while I'm up here. There are, as you can see, a lot of ways to solve the heavy lift problem. That doesn't mean we should try to find a singular solution to all the requirements. This morning we were here looking for the "Holy Grail" to the VTOL problem and to select the single configuration that was going to win. I don't think that is the way it will be solved. Designs must be matched to the job and jobs differ.

QUESTION

(Jim Lematta, Columbia Helicopter Company, Portland, OR)

I want to throw this question or statement into the arena of tandem rotors, or at least a helicopter that does not have a tail rotor, particularly in the medium, heavy lift. The reason I say this is because at one time we operated an S-61 and now we are operating Vertol 107's, and we operated them side-by-side and found that the payloads, because we didn't have a tail rotor on the Vertol, was 2,000 lbs. more, that's 8,000 lbs. on the S-61, and 10,000 lbs. on the Vertol, with identical engines, identical conditions all around. That's because we didn't have to put power into a tail rotor. The difference in power that we estimated was between 12 to 20% which all went to additional lift in the tandem.

Another advantage, I think John hit on earlier, and he is right, we saved 15 to 20 seconds per trip in logging. We computed this out on the 264 days a year we worked at 7 hours of aircraft logging per day. The money saved is over \$4 Million per year! It was because we don't have a tail rotor and therefore can fly any way we wish, sideways and sometimes backwards, just because we don't have a tail rotor. I can't say enough about tandem rotor or a helicopter without a tail rotor, I really can't. That's why we are buying the Chinook. If there was another aircraft that would come along with a tail rotor and we had the option to buy either one we would not consider the one with the tail rotor.